Appendix A

Overview of Related Literature

McDowell, R.W., Sharpley, A.N., Beegle, D.B., Weld, J.L. (2001). "Comparing phosphorus management strategies at a watershed scale." *Journal of Soil and Water Conservation*, 56(4), 306-315.

Starting with the premise that "The ultimate goal of P management is to balance P inputs to farm with outputs in primary production such that no excess P is applied and soil P concentrations are kept at an optimum level for agronomic performance and minimal environmental impact," this article examined three management scenarios of the USDA-EPA *Unified National Strategy for Animal Feeding Operations* to reduce phosphorus from a watershed (p. 306). Using a "site assessment phosphorus index" they found that none of the watershed was at high risk of phosphorus loss and that those areas with medium were near the stream channel. Of the three strategies, the authors endorse the phosphorus index strategy because it can take into account landscape variables that affect phosphorus loss and can "focus on defining, targeting and remediating fields that combine high soil P concentrations with areas of high erosion and overland flow potential," (p. 313). Essentially, this paper endorses the P index management strategy because it can discriminate areas that have the greatest risk of P loss from those that have lower risks of P loss and can, therefore, treat them differently.

Schärer, M., Stamm, C., Vollmer, T., Frossard, E., Oberson, A., Flühler, H., Sinaj, S. (2007). "Reducing phosphorus losses from over-fertilized grassland soils proves difficult in the short term." *Soil Use and Management*, 23(1), 154-164.

This article examines three management options for reducing P runoff from grassland soils. They found that, although omitting the application of P fertilizer would reduce soil P in the long term, more drastic measures were needed to achieve P loss reductions in the short term. They found that establishing a new P equilibrium in the soil takes years and cannot be accelerated, so it is especially important to stop further build-up of P as soon as possible. So, the article essentially says that short-term treatments are inadequate to solve the problem, so stopping further P from being applied is extremely important and is probably the only way to solve the problem.

Hansen, N.C., Daniel, T.C., Sharpley, A.N., Lemunyon, J.L. (2002). "The fate and transport of phosphorus in agricultural systems." *Journal of Soil and Water Conservation*, 57(6), 408-417.

This article investigates the importance of each transport pathway (runoff, soil interflow, deep leaching) as affected by soil type and management. The paper notes that it can take "many years to reduce P concentration in soils with a high STP concentration" (415). The ultimate conclusion that they reach for reducing P losses is site risk assessment; identifying sites with a high potential of P movement to surface water and then implementing management practices to reduce P losses from those sites.

Edwards, D.R., Daniel, T.C., Scott, H.D., Moore Jr., P.A, Murdoch, J.F., Vendrell, P.F. (1997). "Effect of BMP implementation on storm flow quality of two northwestern Arkansas streams." *American Society of Agricultural Engineers*, 40(5), 1311-1319.

This article examined whether a program of Best Management Practice (BMP) is effective at reducing storm stream flow concentrations and mass transport of nutrients. They found that significant decreases (from 23 to 75% per year) in both concentrations and mass transport of nutrients occurred concurrently with BMP implementation.

Kleinman, P.J.A., Sharpley, A.N. (2003). "Effect of broadcast manure on runoff phosphorus concentrations over successive rainfall events." *Journal of Environmental Quality*, 32(1), 1072-1081.

This article evaluates the effects of manure application rate and type on runoff P concentrations. They found that the application rate of manure was related to runoff P due to increased concentrations of dissolved reactive phosphorus in runoff. That is, as the application rate increased, so did the contribution to DRP in runoff TP. Additionally, poultry and swine manure treatments tended to have higher DRP concentrations than runoff from dairy manure treatment. Repeated rainfall diminished the differences in runoff DRP and differential erosion of broadcast manure caused significant differences in runoff TP concentrations between soils. Essentially, increasing rates of manure application were associated with a higher proportion of runoff TP as DRP, which indicates that soluble P losses from manure become increasingly important at higher rates of application.

McDowell, R.W., Sharpley, A.N. (2001). "Approximating phosphorus release from soils to surface runoff and subsurface drainage." *Journal of Environmental Quality*, 30(1), 508-520.

This article investigates the P release from the surface in relation to the concentration of P in surface runoff and subsurface damage. They found a change point above which P increased at a greater rate per unit increase in STP than if below the change point. They note that the change point in STP may be used in support of agricultural and environmental P management.

Sharpley, A.N., McDowell, R.W., Kleinman, P.J.A. (2001). "Phosphorus loss from land to water: integrating agricultural and environmental management." *Plant and Soil*, 237, 287-307.

This article argues that the overall goal of efforts to reduce P loss to water should involve balancing P inputs and outputs at farm and watershed levels by optimizing animal feed rations and land application of P as mineral fertilizer and manure. They found that the loss of P originates primarily from small areas within watersheds during a few storms. These areas are those with high soil P, or P application in mineral fertilizer or manure.

DeLaune, P.B., Moore Jr., P.A., Carman, D.K., Sharpley, A.N., Haggard, B.E., Daniel, T.C. (2004). "Evaluation of the phosphorus source component in the phosphorus index for pastures." *Journal of Environmental Quality*, 33(1), 2192-2200.

This article evaluates the P index for pastures by applying poultry litter to test plots and by evaluating watersheds that had been fertilized with poultry litter for over ten years. The small plots indicated that soil test P, by itself, was a poor predictor of P concentrations in runoff water and that the relationship between P in runoff and the amount of soluble P applied was highly significant. The pastures with natural rainfall and annual poultry litter application indicated that the P index for pastures predicted P loss accurately without calibration. "These data indicate that the P index for pastures can accurately assess the risk of P loss from fields receiving poultry litter applications in Arkansas and provide a more realistic risk assessment than threshold soil test P levels."

Wang, X., Harmel, R.D., Williams, J.R., Harman, W.L. (2006). "Evaluation of EPIC for assessing crop yield, runoff, sediment and nutrient losses from watersheds with poultry litter fertilization." *American Society of Agricultural and Biological Engineers*, 49(1), 47-59.

This article is an evaluation of the Environmental Policy Integrated Climate (EPIC) model version 3060 and looked at runoff of several watersheds when poultry litter was added. The model accurately predicted surface P runoff on an annual, monthly, and daily basis for al watersheds. So, they conclude that EPIC is able to successfully replicate the environmental impact of poultry litter application on runoff, water quality, and crop yields.

DeLaune, P.B., Moore Jr., P.A., Carman, D.K., Sharpley, A.N., Haggard, B.E., Daniel, T.C. (2004). "Development of a phosphorus index for pastures fertilized with poultry liter – factors affecting phosphorus runoff." *Journal of Environmental Quality*, 33(1), 2183-2191.

This article evaluates the effects of multiple variables on P concentrations in runoff water and tries to construct P source component of a P index for pastures that incorporates these effects. Their goal is to see if recent studies that show that other factors are more indicative of P concentrations in runoff from areas where manure is being applied than an upper limit on soil test phosphorus. They found that, without manure, soil test P was directly related to soluble P concentrations in runoff water. After the poultry litter was applied, soil test P had little effect on P runoff. In other words, "once manure was applied, SRP concentrations in runoff were not correlated to Mehlich-III P, but were highly correlated to the SRP concentrations in the applied manure (2189)." So, P runoff increased with increasing soluble P concentration in the manure. They also found that runoff P varied based on the type of manure applied, with alum-treated litter having the lowest P runoff, and commercial P fertilizer and HAP or phytase litter having the highest P runoff.

Manel, K.M., Slates, J.D. (2003). "Farmer Estimates of Manure Application Rates." Symposium, Ninth International Animal, Agricultural and Food Processing Wastes Proceedings, 200-203.

This article looks at the ability of livestock producers and growers to make visual estimates of manure application rates. Of the 101 participants, 13% estimated at or near the actual application rate, 22% estimated high application rates, while 65% underestimated the manure application rate (with 50% estimating less than one-half the actual application rate). Relying on visual estimates without training, 50% would have applied twice the desired application rate. Thus, they conclude that the tendency to underestimate manure application and therefore over-apply manure reinforces the need to calibrate spreading equipment as a part of a manure management plan.

Gitau, M.W., Chaubey, I., Nelson, M.A., Pennington, J.H. (2007). "Analyses of BMP and land use change effects in a Northwest Arkansas agricultural watershed." ASABE Paper N. 072244. St. Joseph, Mich.: ASABE.

This article seeks to quantify the effects of implementation, timing, and spatial distribution of the Best Management Practices (BMPs) on sediment and nutrient loss reduction and watershed ecological integrity. From an analysis of historical land use and BMP implementation, they found a 9% increase in urban areas and an 11% decrease in pastured areas between 1992 and 2004. During this time about 10% of the watershed was in transitional land use, and BMP implementation increased from less than 1% to 34% of the watershed area. Also during this time, sediment loss declined by 22%, total phosphorus losses declined by 11%, and total nitrogen losses increased by 11%.

Kleinman, P.J.A., Sharpley, A.N. (2003). "Effect of broadcast manure on runoff phosphorus concentrations over successive rainfall events." *Journal of Environmental Quality*, 32, 1072-1081.

This article evaluates the effects of manure application rate and type on runoff P concentrations from acidic agricultural soils over successive runoff events. The runoff boxes were broadcast with three types of manure and simulated rainfall was applied. They found that application rate of manure was related to runoff P, due to increased concentrations of dissolved reactive phosphorus in runoff; as application rate increased, so did the concentration of DRP in the runoff total phosphorus. Swine and poultry manure showed higher DRP concentrations in runoff than dairy manure.

White, M.J., Storm D.E., Stoodley, S., Smolen, M.D. (2003). "Modeling the Lake Eucha basin with SWAT in 2000." ASAE November Conference, 536-542.

The SWAT model predicted that the application of poultry litter elevated soil test phosphorus in the basin and is responsible for 49% of the current annual phosphorus load to the lakes.

Sen, S., Srivastava, P., Yoo, K., Dane, J.H., Shaw, J.N., Kang, M.S. (2007). "Runoff generation mechanism in the Appalachian plateau region of Alabama – a field investigation." ASABE Paper No. 072090. St. Joseph, Mich.: ASABE.

This article attempts to delineate spatial and temporal distribution of hydrologically active areas (HAAs) and identify surface runoff generation mechanism using distribution sensors. This research is a response to the failure of Alabama's P-index to account for differences in P loss, from poultry litter, across specific fields within a single watershed. They found that the surface runoff generation mechanism is mostly infiltration excess (rather than saturation excess) and that certain hydrologic characteristics seem to play a dominant role in surface runoff generation in this specific region of Alabama. Additionally, they further conclude that the ability to predict the spatial and temporal distribution of HAAs can be predicted by a few variables, would lead to significantly better management of P from land-applied poultry litter.

Gitau, M.W., Gburek, W.J., Jarrett, A.R. (2005). "A tool for estimating best management practice effectiveness for phosphorus pollution control." *Journal of Soil and Water Conservation*, 60(1), 1-10.

As a response to P runoff from farms that had reached the New York City water supply, this study establishes a means of estimating BMP effectiveness, based on data available in the literature, and develops a tool that allows users to obtain BMP effectiveness estimates for their respective site soil and slope conditions.

Secchi, S., Gassman, P.W., Jha, M., Kurkalova, L., et al. (2007). "The cost of cleaner water: Assessing agricultural pollution reduction at the watershed scale." *Journal of Soil and Water Conservation*, 62(1), 10-21.

This study, performed for the Iowa Department of Natural Resources, outlines a methodology to simultaneously assess economic costs and water quality benefits associated with the hypothetical placement of a broad set of conservation practices. Annual costs range from $300 to $597 million and predicted sediment decreases from 6-65%, total P from 28-59%, and nitrate from 6-20%.

Buczko, U., Kuchenbuch R.O. (2007). "Phosphorus indices as risk-assessment tools in the U.S.A. and Europe – a review." *Journal of Plant Nutrition and Soil Science*, 170, 445-460.

This article reviews the factors of P loss which are taken into account in P indices and different modifications of P indices according to their components and structural approach. Essentially, this article looks at the different P indexes that exist and divides them into three groups: (1) additive approach, (2) multiplicative approach, and (3) multiplicative-aditive approach.

Pote, D.H., Daniel, T.C., Nicholas, D.J., Moore Jr., P.A., Miller, D.M., Edwards, D.R. (1999). "Seasonal and soil-drying effects on runoff phosphorus relationships to soil phosphorus." *Soil Science Society of America Journal*, 63, 1006-1012.

This article investigates the possibility that the correlation between increased concentrations of dissolved reactive P (DRP) in runoff from grassland and increased soil test P (STP) levels are affected by seasonal changes in field conditions and the practice of air-drying soil samples prior to analysis. They found that all correlations of STP to runoff DRP were significant, regardless of seasonal changes or STP method. Additionally, they found that DRP concentration in August runoff was almost double that of May runoff. So, seasonal changes can make a difference.

Tesfaye, D., Storm, D.E., Payton, M.E., Smolen, M.D., Basta, N.T., Zhang, H., Cabrere, M.L. (2004). "Spatial and temporal scaling effects on hydrology and phosphorus loss in runoff from pastures." ASAE Paper No. 042271.

This article attempts to investigate: the interaction of explanatory variables and their effects on response variables, the spatial and temporal scaling effects on hydrology, and DRP and TP losses in runoff from pastures. They found that DRP loss from pastures was significantly influenced by poultry liter, rainfall duration, pasture height, plot size, rainfall intensity, and runoff duration.

Erb, K.A. (2002). "Phosphorus loading per acre vs. cow populations in a dairy watershed in Northeast Wisconsin." ASAE Publication No. 2010P0102.

This article conducted a study to determine per-hectare rate of nitrogen, phosphorus, and potassium loading on farms in the Lower Fox River Basin over two years. The mass balance showed an average of 98 kg/ha nitrogen accumulation, 17kg/ha phosphorus accumulation, and 90 kg/ha potassium accumulation on dairy farms. Cash grain accumulation rates were 10, 3, and 26 kg/ha, respectively. Most of the dairy farms had already implemented nitrogen based nutrient management plans. "The study indicates that phosphorus accumulations could be reduced by more that 90% by implementing a number of additional management practices, including switching to lower phosphorus protein supplements, growing rather than purchasing protein sources, reducing the amount of phosphorus in the dairy ration, and reallocating manure across the farm to fields with the greatest phosphorus need."

Soupier, M.L., Mostaghimi, S., Yagow, E.R. (2006). "Nutrient transport from livestock manure applied to pastureland using phosphorus-based management strategies." *Journal of Environmental Quality*, 35, 1269-1278.

Recognizing that land applications of manure from confined animal systems and direct deposit by grazing animals are both major sources of nutrients in streams, this paper attempts to determine the effects of P-based manure applications on total suspended solids and nutrient losses from dairy manures and poultry litter surface applied to pasturelands and to compare the nutrient losses transported to the edge of the field during overland flow events. The study found that the nutrients are most transportable from cowpies, so a buffer zone between pastureland and streams or other appropriate management practices are necessary to reduce nutrient losses to waterbodies.

Haggard, B.E., Storm, D.E., Stanley, E.H. (2001). "Effect of a point source input on stream nutrient retention." Journal of the American Water Resources Association, 37(5), 1291-1299.

This article examined the effect of a point sources input on water chemistry and nutrient retention in an Arkansas creek. They found that, although no single factor is responsible for nutrient retention, discharge and the level of nutrient enrichment explained a substantial amount of the observed variance in the SRP.

Srinivasan, M.S., Gerard-Marchant, P., Veith, T.L., Gburek, W.J., Steenhuis, T.S. (2005). "Watershed scale modeling of critical source areas of runoff generation and phosphorus transport." Journal of the American Water Resources Association, 361-375.

This article evaluated Soil Moisture Distribution and Routing (SDMR) and SWAT by applying them to a watershed in Pennsylvania in order to identify runoff generation areas. Neither simulation matched the observed data over all seasons, but SWAT is better able to predict time series stream flow. However, neither model allows runoff routing across the watershed.

Kornecki, T.S., Sabbagh, G.J., Storm, D.E. (1999). "Evaluation of runoff, erosion, and phosphorus modeling system – SIMPLE." Journal of the American Water Resources Association, 35(4), 807-820.

This article evaluates the performance of Spatially Integrated Models for Phosphorus Loading and Erosion (SIMPLE) in predicting runoff volume, sediment loss, and phosphorus loading from two watersheds. SIMPLE tended to underestimate runoff volumes during the dormant period and the comparison between observed and predicted dissolved phosphorus showed better correlation than for observed and predicted total phosphorus loading.

Sharpley, A., Kleinman, P., Weld, J. (2004). "Assessment of best management practices to minimize the runoff of manure-borne phosphorus in the United States." *New Zealand Journal of Agricultural Research*, 47, 461-477.

This article demonstrates that the P Index can provide flexible and reliable manure management and provide farmers with options to minimize the risk of P loss.

Kronvang, B., Vagstad, N., Behrendt, H., Bogerstrand, J., Larsen. S.E. (2007). "Phosphorus losses at the catchment scale within Europe: an overview." *Soil Use and Management*, 23(10, 104-116.

This article examines the importance of phosphorus losses from agricultural land by analyzing data and two different models for the Nordic-Baltic region of Europe.

Sharpley, A.N., Weld, J.L., Beegle, D.B., Kleinman, P.J.A., Gburek, W.J., Moore Jr., P.A., Mullins, G. (2003). "Development of phosphorus indices for nutrient management planning strategies in the United States." *Journal of Soil and Water Conservation*, 58(3), 137-152.

This article charts the development of the indexing approach, which ranks site vulnerability to P loss by accounting for source and transport factors and outlines modifications made among States to the P index that reflect local conditions and policy. The conclude that using three management scenarios (changing the time of applied manure, riparian buffer establishment, and reduced feed P ration) that overall P index ratings can be decreased, giving farmers more options for manure management than by simply reducing application rates.

Kleinman, P.J.A., Needelman, B.A., Sharpley, A.N., McDowell, R.W. (2003). "Using soil phosphorus profile data to assess phosphorus leaching potential in manured soils." *Soil Science Society of America Journal*, 67(1), 215-224.

This article investigates whether detailed description and interpretation of soil P profile data provide adequate insight into P leaching potential. They ultimately conclude that soil P profile data appear to provide only limited insight into P leaching potential.

Gaudreau, J.E., Victor, D.M., White, R.H., Provin, T.L., Munster, C.L. (2002). "Response of turf and quality of water runoff to manure and fertilizer." *Journal of Environmental Quality*, 31, 1316-1322.

This article evaluates responses of bermudagrass turf and volumes and P and N concentrations of surface runoff after fertilizer or composted manure applications. They found that runoff volumes were similar between manure and fertilizer sources of P and that dissolved P concentration in runoff during a rain even was five times greater for fertilizer than for manure P.

Kleinman, P.J.A., Sharpley, A.N., Moyer, B.G., Elwinger, G.F. (2002). "Effect of mineral and manure phosphorus sources on runoff phosphorus." *Journal of Environmental Quality*, 31, 2026-2033.

This article attempts to quantify the effects of alternative P sources, application methods, and initial soil P concentrations on runoff P losses from three acidic soils. They found that runoff DRP concentrations were highly correlated with water-soluble P concentration of surface-applied manure. Additionally, practices that increase P sorption at the soil surface may reduce P loss in surface runoff, even after surface application has occurred.

Daniel, T.C., Sharpley, A.N., Lemunyon, J.L. (1998). "Agricultural phosphorus and eutrophication: a symposium overview." *Journal of Environmental Quality*, 27, 251-257.

This article provides an overview of the issues discussed at a symposium titled "Agricultural Phosphorus and Eutrophication." "Generally, the loss of agricultural P in runoff is not of economic importance to a farmer. However, it can lead to significant off-site economic impacts, in some cases occurring many miles from the P source. By the time these impacts are manifest, remedial strategies are often difficult and expensive to implement: they cross political and regional boundaries. . ."

Edwards, D.R., Daniel, T.C. (1994). "Quality of runoff from Fescue grass plots treated with poultry litter and inorganic fertilizer." Journal of Environmental Quality, 23, 579-584.

This article assessed the impacts of fertilizer treatment and simulated rainfalls on quality of runoff from fescue grass. After the first rainfall event, the total P runoff was highest from plots that received inorganic fertilizer, while the highest concentrations of chemical oxygen demand and total suspended solids occurred in runoff from plots treated with poultry litter. The runoff from the second and third rainfall events were not significantly different than the control. So, the first rainfall event is significantly worse than subsequent rainfall events.

Pote, D.H., Daniel, T.C., Sharpley, A.N., Moore Jr., P.A., Edwards, D.R., Nichols, D.J. (1996). "Relating extractable soil phosphorus to phosphorus losses in runoff." Soil Science Society of America Journal, 60, 855-859.

This paper tested the hypothesis that soil test P correlates to dissolved reactive P and bioavailable P in runoff varies, depending on the extraction method. They found that there is a linear relationship between STP levels and DRP concentration in runoff from the soil surface.

Sauer, T.J., Daniel, T.C., Moore Jr., P.A., Coffey, K.P., Nichols, D.J., West, C.P. (1999). "Poultry litter and grazing animal waste effects on runoff water quality." *Journal of Environmental Quality*, 28, 860-865.

This study compares the effects of grazing animal depositions vs. poultry litter application on nutrient runoff. Plots receiving poultry litter had significantly greater losses of most nutrient parameters for both rainfall simulations. They ultimately concluded that "a severe rainfall event shortly after poultry litter application produces significantly greater nutrient losses as compared to similar application of grazing animal depositions at the rates used in the experiment.

Edwards, D.R., Daniel, T.C. (1992). "Environmental impacts of on-farm poultry waste disposal – a review." *Biosource Technology*, 41, 9-33.

This paper reviews information regarding the disposal of on-farm poultry wastes and the effects of poultry waste disposal on environmental quality.

Edwards, D.R., Daniel, T.C., Scott, H.D., Murdoch, J.F., Habiger, M.J., Burks, H.M. (1996) "Stream quality impacts of best management practices in a Northwestern Arkansas basin." Water Resources Bulletin, 32(3), 499-509.

This article attempts to asses the water quality effectiveness of best management practices implemented in the Lincoln Lake basin in Northwest Arkansas. Total P was highest for sub-basins with the highest proportion of pasture land use. The declines in analysis parameter concentrations are attributed to the implementation of BMPs in the basin.

Pote, D.H., Daniel, T.C., Nichols, D.J., Sharpley, A.N., Moore Jr. P.A., Miller, D.M., Edwards, D.R. (1999). "Relationship between phosphorus levels in three ultisols and phosphorus concentrations in runoff." *Journal of Environmental Quality*, 28, 170-175.

This study attempts to identify the most consistent STP method for predicting runoff DRP levels, and determine effects of site hydrology on correlations between runoff DRP concentrations. They found that all correlations of STP to runoff DRP were significant, which suggests the importance of site hydrology in determining P loss in runoff and may provide a means of developing a single relationship for a range of soil series.

Nelson, M.A., Cash, W.L., Steele, K.F. (2000). "Determination of nutrient loads in Upper Moores Creek." Arkansas Soil & Water Conservation Commission.

This is a report of a monitoring project of the Lincoln Lake Basin in order to demonstrate the effectiveness of the implemented BMPs in reducing nutrient transport from the pastures in the intensively managed areas.

Chapman, S.L., Moore, B.J., Barton, L. "Water quality and poultry production in three hydrologic units in Arkansas." University of Arkansas Cooperative Extension Service.

This is a report on three USDA hydrologic projects in Arkansas. They found that, although only about 30% of the soils need phosphorus fertilization for crop production, however producers continue to apply poultry litter to the land.

Sauer, T.J., Daniel, T.C., Moore Jr., P.A., Coffey, K.P., Nichols, D.J., West, C.P. (1999). "Poultry litter and grazing animal waste effects on runoff water quality." *Journal of Environmental Quality*, 28(3), 860-865.

This study compares nutrient runoff as affected by grazing animal depositions vs. poultry litter application. They found that plots receiving poultry litter had significantly greater losses of most nutrient parameters. "A severe rainfall event shortly after poultry litter application produces significantly greater nutrient losses as compared to similar application of grazing animal depositions."

Moog, D.B., Whiting, P.J. (2002). "Climatic and agricultural factors in nutrient exports from two watersheds in Ohio." *Journal of Environmental Quality*, 31, 72-83.

This article uses a statistical analysis to identify climatic, hydrologic, and agricultural variables that best explain variations in nitrate, phosphorus, and total suspended solids between 1976 and 1995 in two watersheds that feed Lake Erie. Nitrate, total suspended solids, and total phosphorus tended to decrease when previous months were wet, except in the summer, and to decrease when snow cover was extensive. Soluble reactive phosphorus loads were negatively correlated to conservation tillage and reserves, and positively correlated to fertilizer and manure sources.

Lehmann, J., Lan, Z., Hyland, C., Sato, S., Solomon, D., Ketterings, Q.M. (2005). "Long-term dynamics of phosphorus forms and retention in manure-amended soils." Environmental Science and Technology, 39, 6672-6680.

This study investigates the relationship between organic and inorganic P in soil pools and equilibrium leachate along a chronosequence of poultry and dairy manure additions in New York. They found that long-term manuring resulted in the low retention of additional P in the soil.

Sauer, T.J., Daniel, T.C., Nichols, D.J., West, C.P., Moore Jr., P.A., Wheeler, G.L. (2000). "Runoff water quality from poultry litter-treated pasture and forest sites." *Journal of Environmental Quality*, 29, 515-521.

This study attempts to measure the effect of site characteristics and poultry litter application on runoff and nutrient transport from grazed pasture and forest sites at different landscape positions. They found that poultry litter-treated plots had consistently higher concentrations of all water quality parameters tested compared to untreated plots. Additionally, concentration of DRP in runoff from untreated plots was linearly correlated with three soil P tests and soil P on litter-treated plots had little effect on runoff DRP. Finally, the results indicate that variation in runoff has a significant effect on nutrient transport from grazed pastures receiving poultry litter.

Maguire, R.O., Hesterberg, D., Gernat, A., Anderson, K., Wineland, M., Grimes, J. (2006). "Liming poultry manures to decrease soluble phosphorus and suppress the bacteria population." *Journal of Environmental Quality*, 35, 849-857.

This study evaluated the ability of CaO and CA2 for killing manure bacterial populations and stabilizing P in poultry wastes and to investigate the influence on soils following amendment with treated wastes. They found that the liming process, when used successfully, reduced plate counts and concerns about P losses in runoff following land application.

Sharpley, A., Foy, B., Withers, P. (2000). "Practical and innovative measures for the control of agricultural phosphorus losses to water: an overview." *Journal of Environmental Quality*, 29(1), 1-9.

This paper provides an overview of P management strategies to maintain agricultural production and protect water quality that were discussed at a conference. They concluded that there are many ways to control agricultural P transfer from soil to water including: optimizing fertilizer P use-efficiency, refining animal feed rations, using feed additives to increase P absorption by the animal, moving manure from surplus to deficit areas, and targeting conservation practices.

Nolen, S.L., Carroll, J.H., Combs, D.L., Staves, J.C. (1989). "Limnology of Tenkiller Ferry Lake, Oklahoma, 1985-1986." Proceedings of the Oklahoma Academy of Science, 69, 45-55.

This study is a response to deteriorating water quality in various watersheds, specifically the Illinois River Basin. The purpose of this study was to collect sufficient baseline water quality data to define current limnological conditions at Tenkiller Lake and to provide a basis for future water quality protection and monitoring.

Vadas, P.A., Krogstad, T., Sharpley, A.N. (2006). "Modeling phosphorus labile and nonlabile soil pools: updating the EPIC model." *Soil Science Society of America Journal*, 70, 736-743.

This study attempts to determine if replacing EPIC's constant sorption and desorption rate factor with more dynamic rate factors can more accurately predict changes in soil labile P on addition to and depletion of P from soils. They recommend improvements to EPIC's sorption and desorption rate factors by making them dynamic.

Vadas, P.A., Haggard, B.E., Gburek, W.J. (2005). "Predicting dissolved phosphorus in runoff from manured field plots." *Journal of Environmental Quality*, 34, 1347-1353.

This article tests a previously proposed model to predict manure P in runoff. It finds that, using independent field-plot data, original under predictions of manure runoff P can be improved by calculating P distribution fractions from measured runoff to rain ratios or adjusting runoff to rain ratios based on their degree of error.

Vadas, P.A., Harmel, R.D., Kleinman, P.J.A. (2007). "Transformations of soil and manure phosphorus after surface application of manure to field plots." Nutrition Cycle Agroecosystems, 77, 83-99.

This study monitors the manure and soil P over 14 to 17 months in field experiments in Texas and Pennsylvania following dairy and poultry manure surface application. They found that manure mass consistently decreased while manure total P was essentially constant through time. They ultimately concluded that management practices for water quality protection must consider the potential for manure P transformations to contribute dissolved P to runoff long after manure is applied.

Haggard, B.E., Soerens, T.S. (2006). "Sediment phosphorus release at a small impoundment on the Illinois River, Arkansas, and Oklahoma, USA." *Ecological Engineering*, 28, 280-287.

The purpose of this study is to evaluate P release from sediments accumulated at a small impoundment where the Illinois River flows from Arkansas into Oklahoma. They find that it is possible that the impound increases dissolved P concentrations in the Illinois River.

White, M.J., Storm, D.E., Zhang, H., Smolen, M.D. "PPM Plus: a tool to aid in nutrient management plan development." Oklahoma Cooperative Extension Service.

This article provides a general overview of PPM Plus and its applications for nutrient management planners and farm managers to evaluate the effect of BMPs before implementation.

Mcdowell, R., Sharply, A., Brookes, P., Poulton, P. (2001). "Relationship between soil test phosphorus and phosphorus release to solution." *Soil Science*, 166(2), 137-149.

This article examines the existence and behavior of a change point in soil P release. The change point is the point above which $CaCl_2$-P increases much more rapidly per unit increase in STP (soil test P) than if it is below that point. The change point varies greatly between soils and in relation to management. The change point can be predicted to within 40% after relatively few samples (as few as 8), and the 40% level is acceptable because most change points are more than 40% of the optimum STP required for plant growth. Essentially, putting phosphorus onto the ground in levels that far exceed the amount desired for plant growth, causes P levels to increase much more rapidly than it does at lower levels.

Vadas, P.A., Kleinman, P.J.A., Sharpley, A.N., Turner, B.L. (2005). "Relating soil phosphorus to dissolved phosphorus in runoff: a single extraction coefficient for water quality modeling." *Journal of Environmental Quality*, 34(1), 572-580.

This article investigates the extradition coefficients of water-extractable soil P and soil P sorption saturation. They found that the relationship between soil P sorption saturation and runoff FRP was the same for all 10 soils investigated, and exhibited a split-line relationship where runoff FRP rapidly increased at P sorption saturation values greater than 12.5%. They concluded that a test for soil P saturation may provide the most universal prediction of dissolved P in runoff, but only for non-calcareous soils. So, essentially, they found that a single value for an extradition coefficient relating to soil P can be used across a wide range of soil, hydrology, or management scenarios. Thus, this article can be used to counter the argument that a specific location is unique and that traditional modeling practices, therefore, do not apply to it.

Vadas, P.A., Gburek, W.J., Sharpley, A.N., Kleinman, P.J.A., Moore Jr., P.A., Cabrera, M.L., Harmel, R.D. (2007). "A model for phosphorus transformation and runoff loss for surface-applied maures." *Journal of Environmental Quality*, 36(1), 324-332.

This article develops a model to assess P release and transport from surface manures. It looked at data from Texas, Pennsylvania, Georgia, and Arkansas and found that 80% of the P remains in the top 2 cm, while 20% leaches deeper. The model can differentiate the effects of the sources of P in the soil, machine-applied manure, and manure applied from grazing animals. This model can help target alternative management practices that will be most effective in mitigating P loss. There is also some discussion in this article about the application of poultry manure in Arkansas.

Vadas, P.A., Kleinman, P.J.A., Sharpley, A.N. (2004). "A simple method to predict dissolved phosphorus in runoff from surface-applied manures." *Journal of Environmental Quality*, 33(1), 749-756.

This article details a simple approach to predict dissolved P release from manures based on observed trends in laboratory extraction of P in dairy, poultry, and swine manures with water over different water to manure ratios. The method was able to predict dissolved inorganic P concentrations in runoff from surface-applied manures, which indicates its potential to improve water quality models.

Sharpley, A.N., Kleinman, P.J.A., McDowell, Gitau, M., Bryant, R.B. (2002). "Modeling phosphorus transport in agricultural watersheds: processes and possibilities." *Journal of Soil and Water Conservation*, 57(6), 425-439.

This article looks at the challenges of modeling P transport and provides a conceptual framework from which process-based P transport models might be evaluated. They found that, although extraction coefficients relating soil and flow P are variable, they can be represented as a function of land cover or erosion. The article emphasizes improving current models to accurately predict P transport.

Chaubey, I., Sahoo, D., Haggard, B.E., Matlock, M.D., Costello, T.A. (2007). "Nutrient retention, nutrient limitation, and sediment-nutrient interactions in a pasture-dominated stream." *American Society of Agricultural and Biological Engineers*, 50(1), 35-44.

This article examines the effects of nutrients in a watershed in Arkansas. They found that light, not nutrients, limited algal growth. They concluded that "even nutrient-rich streams may continue to assimilate, to some extent, increased loads of P, altering the timing and magnitude of downstream transport of P.

Appendix B

Illinois River Watershed Phosphorus Mass Balance Study

Alexander
Consulting, Inc.

Illinois River Watershed Phosphorus Mass Balance Study

Prepared under the direction of:

Bernie Engel, Ph.D.
Purdue University
225 South University Street
West Lafayette, Indiana 47907
(765) 494-1162
(765) 496-1115 - Fax

Thomas J. Alexander, Ph.D.
Alexander Consulting, Inc.
5802 South 129th East Avenue
Tulsa, Oklahoma 74134
(918) 307-0068
(918) 459-0138 – Fax

By:
Meagan Smith
Meagan Smith
5802 South 129th East Avenue
Tulsa, Oklahoma 74134
(918) 307-0068
(918) 459-0138 - Fax

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

1.0 EXECUTIVE SUMMARY

A phosphorus mass balance study was performed on the Illinois River Watershed (IRW). The purpose of the study was to determine the source(s) of phosphorus causing eutrophication of Tenkiller Ferry Reservoir and water quality degradation of the Illinois River and its tributaries.

Based on the findings of the study, the following can be concluded:

1. Poultry production is currently responsible for more than 76% of the net annual phosphorus additions to the IRW.
2. Historical data indicates poultry production has been the major contributor of phosphorus to the watershed since 1964. Prior to 1964, dairy cattle were responsible for the majority of the phosphorus contribution.
3. From 1949 to 2002, there was more than 219,000 tons of phosphorus added to the IRW. Almost 68% of that addition, more than 148,000 tons, was attributable to poultry production.
4. Other contributing sources of phosphorus (net additions) include commercial fertilizers (7.5%), dairy cattle (5.2%), humans (3.2%), swine (2.9%), industrial sources – mostly poultry processing facilities (2.7%) and beef cattle (1.7%). The remaining sources of phosphorus evaluated in this study, which include urban runoff, golf courses, wholesale nurseries, and recreational users, are negligible (< 1%).
5. Of the three phosphorus exports from the watershed (harvested crops, harvested deer, and water leaving Lake Tenkiller through the spillway) outflow of phosphorus through the spillway at the south end of Lake Tenkiller was the largest. According to current estimates, the flow of water through the spillway removes just under 1.25% of the total annual phosphorus additions to the watershed. The remaining two phosphorus exports combined remove just over 0.25% of current annual phosphorus additions to the watershed, totaling a 1.5% removal of current phosphorus additions.

2.0 BACKGROUND AND OBJECTIVE

The Illinois River Watershed encompasses nearly 1,052,000 acres (1,644 square miles) in northeast Oklahoma and northwest Arkansas. The watershed spans seven counties and feeds the largest reservoir in Eastern Oklahoma, Tenkiller Ferry Reservoir (known locally as Lake Tenkiller). The seven counties in the watershed include Adair, Cherokee, Delaware, and Sequoyah Counties in Oklahoma; and Benton, Crawford, and Washington Counties in Arkansas. The very small portion of Crawford County, Arkansas that lies within the watershed boundary (just over 1,000 acres) was not included in this study.

The Illinois River was designated a "Wild and Scenic River" in 1970 and benefits from the state protection this designation provides. This protection promotes tourism in the watershed, which sees its peak between April and September when stream flow and temperatures are best for river activities (OSRC, 1998). The main recreational activity in the watershed is canoeing/kayaking, but other activities include camping, fishing, hiking, hunting, horseback riding, wildlife viewing, and sightseeing.

Reports of diminishing water quality caused by eutrophication of Lake Tenkiller and the water quality degradation of the Illinois River its tributaries have prompted concern from both local citizens and state officials (Haraughty, 1999). The eutrophication has been attributed to excess nutrients, specifically phosphorus. The objective of this study was to perform a mass balance on the IRW to determine the source(s) of this phosphorus.

3.0 APPROACH

The outline and approach for the phosphorus mass balance study of the IRW was established by Bernie Engel, Ph.D., Thomas Alexander, Ph.D., and Meagan Smith.

The first step in the study was to identify all phosphorus additions and removals within the watershed, including related assumptions. This was accomplished by first determining which additions and removals are true sources and subtractions of phosphorus; that is, they add phosphorus to or remove phosphorus from the watershed, not just recycle the phosphorus within the watershed.

The next step was to quantify all additions and removals, by source, on an annual basis. Both current and historical values were calculated in order to establish any phosphorus related trends in the watershed, as well as to aid in evaluating the historical impact the added phosphorus has had on the watershed. A mass balance could then be performed based on the calculated values.

Coupling the determined approach with a detailed literature review, the following phosphorus additions and removals were identified.

3.1 Phosphorus Additions

1. Publicly owned treatment works (POTWs) and Septic systems – Not specifically an addition. All phosphorus additions from human excrement were accounted for individually, based on the overall human population in the watershed, not by wastewater treatment plant (WWTP) discharge or septic system releases. This is based on the assumption that all treated wastewater sludge, whether from a WWTP or septic system, is eventually land applied within the basin.
2. Farm animal wastes – Addition (for poultry, swine, dairy cattle, and beef cows and heifers that calved). The additions for poultry, swine and dairy cattle are based on the phosphorus content of their wastes and assume all feed for the animals is imported to the watershed. It is assumed all litter and manure produced in the watershed is land applied in the watershed (Fisher, 2008 and Copenhaver, 1991). Phosphorus additions due to beef cows and heifers that calved are accounted for based on the phosphorus content of protein supplements fed to calving beef cattle (Lalman, 2004). No other portion of beef cattle waste is considered because beef cattle are an otherwise foraging livestock that recycle the phosphorus already in the landscape (Lalman, 2004 and Slaton

et al., 2004). Based on livestock data from the 2002 Census of Agriculture, the population numbers of all other livestock compared with the population numbers of poultry, swine, and cattle were insignificant and therefore, not considered.

3. Non-manure fertilizer application to agricultural land – Addition
4. Golf course fertilizer application – Addition
5. Urbanized areas – Addition. It is assumed this input (urban runoff) will account for all residential fertilizer application, domestic pet waste, and other phosphorus in storm water runoff.
6. Plant nurseries – Addition. Additions related to wholesale plant nurseries are accounted for using tailwater phosphorus concentrations.
7. Recreational users – Addition
8. Industrial sources (manufacturing and processing) – Addition

3.2 Phosphorus Removals

1. Crop consumption/removal from watershed – Removal. The calculations for this phosphorus removal assume all crops grown in the watershed are removed from the watershed upon harvest. The only exception to this assumption is hay/forage crops. It is assumed all harvested forage crops are used for livestock in the IRW and that for every bale of hay that may leave the IRW, an equal amount is brought into the IRW. This results in no phosphorus removal due to the harvest of forage crops.
2. Farm animal consumption/subsequent removal from watershed – Removal for beef cattle only. This is based on all beef cattle in the watershed being foraging animals, therefore recycling phosphorus, with only beef cows and heifers that calved given protein supplements, representing any phosphorus addition (Slaton et al., 2004 and Lalman, 2004). Beef cattle recycle phosphorus until they are sold and subsequently removed from the watershed, at which point all stored phosphorus is removed. Although poultry and swine are also sold and removed from the watershed, they do not remove phosphorus from the watershed because they are non-grazing animals. Based on livestock data from the 2002 Census of Agriculture, the population numbers of all other livestock populations compared with the population numbers of poultry, swine, and cattle are deemed insignificant, therefore any percentage sold out of the watershed represent a negligible removal of phosphorus.

3. Indigenous animals – Removal for harvested deer, only. These animals act to recycle phosphorus in the watershed. They are not introducing more phosphorus nor permanently removing phosphorus. The only indigenous animals permanently removing phosphorus from the watershed are deer harvested during hunting season.
4. Water leaving through spillway on Lake Tenkiller – Removal. There is a quantifiable amount of phosphorus leaving through the spillway at the south end of Lake Tenkiller.

3.3 Other Phosphorus Additions and Removals Considered

1. Indigenous animals (other than harvested deer) – Not an addition or removal. This was based on the assumption that indigenous animals are recycling phosphorus in the watershed through grazing, defecation, bodily decay, etc., not introducing more phosphorus nor permanently removing phosphorus.
2. Solid waste disposal sites – Not an addition. Solid waste disposal facilities must operate leachate collection/treatment systems, therefore eliminating them as a source of phosphorus (EPA, 40 CFR Part 258 Subpart C).
3 Mining operations – Not an addition or removal. The only mining operations in the area are for gravel and sand, which do not introduce phosphorus to the watershed. It is assumed any soils removed by mining are deposited elsewhere in the watershed. This results in no addition or removal of phosphorus through mining.
4. Sedimentation/Erosion – Not an addition or removal. Although there is aeolian and alluvial erosion occurring throughout the watershed, there is also sedimentation/deposition occurring throughout the watershed. All eroded material is captured within the watershed or reservoir, leading to no net addition or removal of phosphorus due to erosion, sedimentation, or deposition.
5. Unmanaged land (riparian areas, forests, grasslands, etc.) – Not a removal. These land areas recycle phosphorus through the natural growth and decay of plant matter. They do not introduce or permanently remove phosphorus (Daniels et al., 2000).
6. Golf course grass uptake – Not a removal. Golf courses typically mulch/compost their clippings on property (G. Hallett, personal communication, 7 August 2006). This leads to a recycling of phosphorus, not a removal of phosphorus.

Figure 1 depicts all phosphorus additions and removals from the IRW, as well as those processes which recycle phosphorus within the watershed.

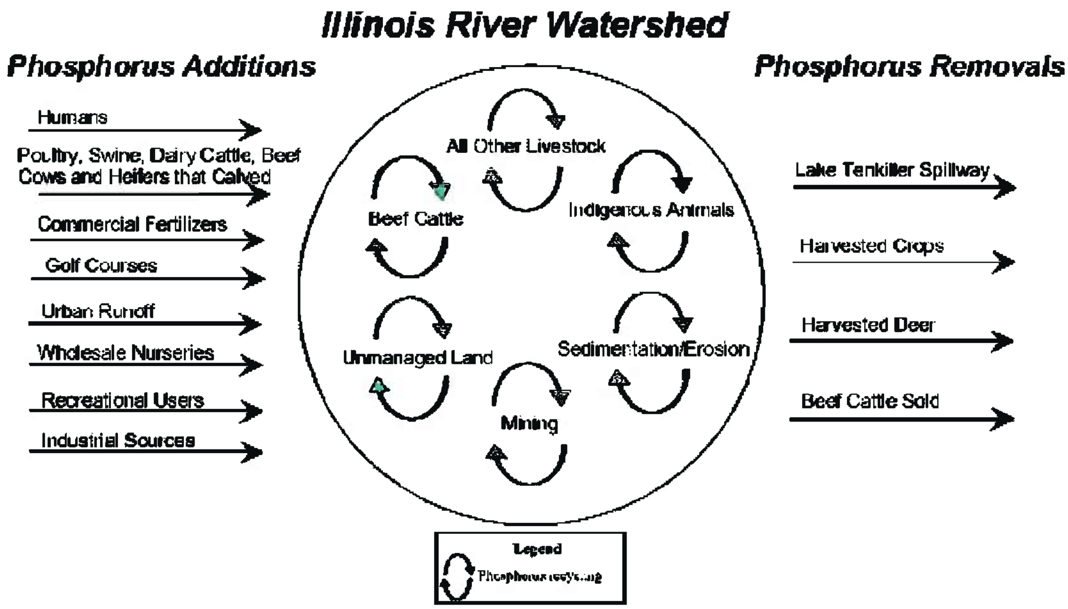

Figure 1. Phosphorus mass balance flow diagram for the Illinois River Watershed.

4.0 PHOSPHORUS CALCULATIONS

After all potential sources of phosphorus to and removals of phosphorus from the watershed were determined, these source contributions and removals were quantified on an annual basis. Both current and historical values were calculated. This was done in order to determine any phosphorus related trends in the watershed, as well as to aid in evaluating the historical impact on the watershed.

4.1 Land Use/Land Cover

Unless otherwise noted, all land use/land cover data used for this study is from the National Land Cover Dataset (NLCD) 2001, summarized by Dr. Robert van Waasbergen (van Waasbergen, personal communication, 2007). The NLCD 2001 was put together by the Multi-Resolution Land Characteristics Consortium (MRLC) and is derived from 30-meter resolution Landsat satellite imagery. There are 29 total land use classes in the data set with only 15 of those classes found in this watershed. The 15 land use classes were grouped into five categories; water, developed, forest, pasture, and crop, as shown below.

1) Open Water - Water
2) Developed, Open Space - Developed
3) Developed, Low Intensity - Developed
4) Developed, Medium Intensity - Developed
5) Developed, High Intensity - Developed
6) Barren Land (Rock/Sand/Clay) - Developed
7) Deciduous Forest - Forest
8) Evergreen Forest - Forest
9) Mixed Forest - Forest
10) Shrub/Scrub - Pasture
11) Grassland/Herbaceous - Pasture
12) Pasture/Hay - Pasture
13) Cultivated Crops - Crops
14) Woody Wetlands - Forest
15) Emergent Herbaceous Wetlands - Pasture

Table 1 shows the amount of each land use/land cover type, in acres, for the entire counties that make up the IRW and the portions of those counties that lie in the IRW. The NLCD 2001 was used for both current and historical calculations.

Table 1. Land use/Land cover for the IRW in acres

County	Water	Developed	Forest	Pasture	Crop	Total
	Land Use/Land Cover Acres					
	Entire County					
Adair	668	16,714	209,486	142,120	325	369,313
Benton	22,020	61,902	231,008	247,725	722	563,377
Cherokee	16,368	25,535	268,179	186,520	267	496,868
Delaware	35,042	28,813	219,619	219,868	3,711	507,053
Sequoyah	24,362	25,727	195,710	203,569	7,653	457,020
Washington	4,109	53,045	301,119	253,091	528	611,892
	IRW Portions					
County	**Water**	**Developed**	**Forest**	**Pasture**	**Crop**	**Total**
Adair	263	12,744	128,395	113,515	264	255,180
Benton	677	26,076	47,256	111,483	272	185,765
Cherokee	10,218	13,818	132,719	66,465	92	223,312
Delaware	35	2,975	26,077	19,710	101	48,897
Sequoyah	3,432	2,987	22,451	17,232	376	46,479
Washington	862	33,589	102,962	154,380	370	292,163
Watershed	15,486	92,189	459,860	482,785	1,476	1,051,796

4.2 Phosphorus Additions

4.2.1 Human Population

The phosphorus additions attributable to the human population in the watershed were accounted for individually, as untreated waste additions. The conservative assumption made to support this method is that all treated discharge water and sludge from both WWTPs and septic systems are eventually released into the watershed.

In order to perform the calculations, it was necessary to determine the phosphorus contributing human population in the watershed. This was done using population numbers from the United States Census Bureau sorted by county areas and total watershed areas calculated in ArcGIS (van Waasbergen, 2007). First, countywide populations were taken from the 1950, 1960, 1970, 1980, 1990, and 2000 U.S. Census. Next, all urban centers over 1,000 people located partially or entirely within the boundary of the IRW, were isolated. The populations of the urban centers in each county were then subtracted from the total county populations. The resulting rural population numbers for each county were multiplied by the percent of the rural area for each county located within the IRW and then summed. This resulted in the rural population for the IRW for each of the six U.S. Census years. The population of all urban centers located partially or entirely within the boundary of the IRW was then added to the rural population numbers to account for all phosphorus additions due to humans. Table 2 shows the IRW populations (accounted for in each county of the IRW) every ten years starting in 1950.

Table 2. Human population in the IRW

Total Population - Illinois River Watershed							
Year	Adair	Benton	Cherokee	Delaware	Sequoyah	Washington	IRW
1950	10,824	21,729	11,079	1,415	1,703	37,125	83,874
1960	9,614	24,050	11,139	1,150	1,701	43,899	91,552
1970	11,077	37,156	15,441	1,361	2,242	58,218	125,496
1980	13,839	55,854	18,197	1,773	1,897	74,135	165,695
1990	13,927	69,460	20,910	2,096	2,009	84,036	192,439
2000	15,987	111,255	26,931	2,829	2,387	120,993	280,383

Two different phosphorus generation rates for the human population were identified: *Septic System Performance: A Study at Dunoon, Northern NSW* (Sarac et al., 2001) and chapter four of the Agricultural Waste Management Field Handbook (USDA, 1992) combined with Mean Body Weight, Height, and Body Mass Index, United States 1960-2002 (CDC, 2004). Sarac et al. (2001) determined annual per capita phosphorus generation rate of 1.1 lb of total phosphorus. The Agricultural Waste Management Field Handbook (USDA, 1992) breaks down the human phosphorus generation rate to 0.02 lb/day/AU of excreted phosphorus, where an AU equals 1000 lb animal live weight. Due to the ability to account for the increase in weight of the average person over the last several decades, it was concluded the preferable resource to utilize was the Agricultural Waste Management Field Handbook (USDA, 1992). Table 3 compares the phosphorus contributions of both waste characterization estimates.

Table 3. Comparison of annual phosphorus additions from humans in the IRW (tons/yr)

Phosphorus Additions (tons/yr) – Humans		
Year	USDA	Sarac et al.
1950	45	46
1960	51	50
1970	73	69
1980	97	91
1990	118	106
2000	182	154

4.2.2 Livestock

The process used to calculate phosphorus production for the various livestock in the watershed was similar to that used to calculate human phosphorus production. Livestock population numbers were combined with phosphorus production rates to determine annual phosphorus contributions for each livestock category.

The countywide livestock populations, both current inventory and livestock sold, depending on the animal type, were obtained from the United States Census of Agriculture (Ag Census) for years 1949, 1954, 1959, 1964, 1969, 1974, 1978, 1982, 1987, 1992, 1997, and 2002. Currently, the Census of Agriculture is conducted by the United States Department of Agriculture, but prior to 1997 the United States Census Bureau conducted the census.

After studying the various livestock population trends in the watershed, it was decided only those animals for which feed is imported into the watershed would be considered. These animals include poultry (broilers, layers, pullets, and turkeys), swine, dairy cattle, and beef cows and heifers that calved. It is assumed all calving beef cattle are fed a protein supplement in addition to their regular foraging (Lalman, 2004). Further, it is assumed all other livestock are grazing livestock, and therefore do not account for a net addition of phosphorus to the watershed (Slaton et al., 2004).

The livestock populations for each portion of county within the IRW were determined based on the percentage of pasture acreage for each county that lies inside the watershed boundary (Nelson et al., 2002). For example, if 10% of the pasture acreage for any given county lies within the boundary of the watershed, then it was assumed that 10% of the livestock population for that county resided within the watershed. This method of livestock distribution was based on the assumption that livestock would not be housed or grazed on cropland, forests, or developed areas and would be equally distributed on pasture (Nelson et al., 2002). The livestock populations accounted for include the number of broilers and turkeys sold from the watershed; the number of layers, pullets, and swine both sold from the watershed and on-hand at the time of each census; the on-hand inventory of dairy cattle at the time of each census; and the on-hand inventory of beef cows and heifers that calved. If data was not available in the Ag Census, a population of zero was assumed, resulting in a zero contribution. The calculations resulted in the current and historical phosphorus contributing livestock populations provided in Table 4.

Table 4. Phosphorus contributing livestock populations in the IRW

Livestock Populations in the Illinois River Watershed								
Year	Broilers	Layers	Pullets	Turkeys	Total Poultry	Swine	Dairy Cattle	Beef Cows & Heifers that Calved
1949	11,924,434	a	a	38,497	**11,962,932**	79,556	29,478	10,379
1954	18,617,043	a	a	302,795	**18,919,838**	38,281	29,877	19,842
1959	35,685,225	a	a	489,136	**36,174,360**	50,939	21,253	29,742
1964	60,681,482	1,759,742	a	a	**62,441,223**	28,423	14,886	50,503
1969	75,718,474	6,687,861	a	a	**82,406,334**	44,297	11,674	62,321
1974	80,779,485	3,881,138	a	b	**84,660,623**	57,064	9,302	86,725
1978	87,085,705	6,358,778	4,041,266	2,274,966	**99,760,715**	212,851	11,771	79,062
1982	91,645,666	7,730,130	3,951,899	2,899,320	**106,227,014**	284,402	15,620	83,235
1987	100,090,686	9,386,334	4,354,641	5,443,358	**119,275,019**	484,617	13,095	81,212
1992	124,834,505	7,550,895	4,476,492	4,013,895	**140,875,787**	324,755	12,148	85,408
1997	126,788,271	5,895,940	3,503,572	4,780,619	**140,968,402**	299,286	9,958	97,440
2002	139,700,237	4,870,617	3,186,207	4,024,094	**151,781,155**	208,243	10,280	101,367

[a]No information listed in Ag Census.
[b]Data listed as not available in Ag Census.

Table 5 presents the same livestock numbers in terms of animal units (AUs), or 1000 lb of animal liveweight. Due to the vast size difference of the animals listed, this allows for a better comparison of the "amount" of each animal type in the watershed. Average liveweights at market were used to determine the AUs. The average liveweights for broilers and turkeys have increased greatly over the past several decades. That increase was accounted for by using their liveweights at market taken from the Poultry Yearbook (ERS, 2006) for years 1964 through 2002. Prior to 1964, the liveweights for broilers and turkeys were estimated using a linear regression. The liveweights for broilers and turkeys are provided in Table 6. The average liveweights at market used to calculate the AUs for the remaining animals are 1375 lb for dairy cattle, 963 lb for beef cows and heifers that calved, 155 lb for swine (ASAE, 2005), 4 lb for layers (ASAE, 2003), and assuming a layer is a full-grown pullet, 2 lb for pullets. These liveweights at market are current estimates and are used to calculate both current and historical AUs in the watershed.

Table 5. Phosphorus contributing livestock populations in the IRW in terms of Animal Units

Livestock Populations in terms of Animal Units***								
Year	Broilers	Layers	Pullets	Turkeys	Total Poultry	Swine	Dairy Cattle	Beef Cows & Heifers that Calved
1949	32,792	*	*	530	33,323	12,331	40,532	9,995
1954	55,106	*	*	4,481	59,588	5,934	41,081	19,108
1959	113,122	*	*	7,743	120,865	7,896	29,222	28,641
1964	211,172	7,039	*	*	218,211	4,406	20,469	48,635
1969	272,587	26,751	*	*	299,338	6,866	16,052	60,015
1974	305,346	15,525	*	**	320,871	8,845	12,790	83,516
1978	337,893	25,435	8,083	43,202	414,612	32,992	16,185	76,136
1982	370,248	30,921	7,904	55,754	464,827	44,082	21,477	80,156
1987	430,390	37,545	8,709	110,555	587,199	75,116	18,006	78,207
1992	561,755	30,204	8,953	87,142	688,053	50,337	16,704	82,248
1997	609,852	23,584	7,007	114,544	754,986	46,389	13,693	93,835
2002	716,662	19,482	6,372	107,685	850,202	32,278	14,135	97,616

[a]1000 lbs of animal liveweight.
[b]No information listed in the Ag Census.
[c]Data listed as not available in the Ag Census.

Table 6. Historical liveweights at market for broilers and turkeys

Liveweights at Market for Broilers and Turkeys (lb)		
Year	Broilers	Turkeys
1949	2.75	13.78
1954	2.96	14.80
1959	3.17	15.83
1964	3.48	17.94
1969	3.60	18.95
1974	3.78	18.35
1978	3.88	18.99
1982	4.04	19.23
1987	4.30	20.31
1992	4.50	21.71
1997	4.81	23.96
2002	5.13	26.76

The historical animal populations in the watershed are represented graphically in Figures 2 and 3. Figure 2 depicts the historical animal population numbers and Figure 3 depicts the populations in terms of animal units.

After determining livestock populations for the watershed, multiple sources were considered to calculate the phosphorus addition for each population. The various phosphorus generation rates were combined with liveweight estimates and standard animal growth cycles, when needed, in order to calculate and compare the overall phosphorus additions from each livestock source. Standard growth cycles were used to account for multiple rotations of animals raised on a farm in a given year.

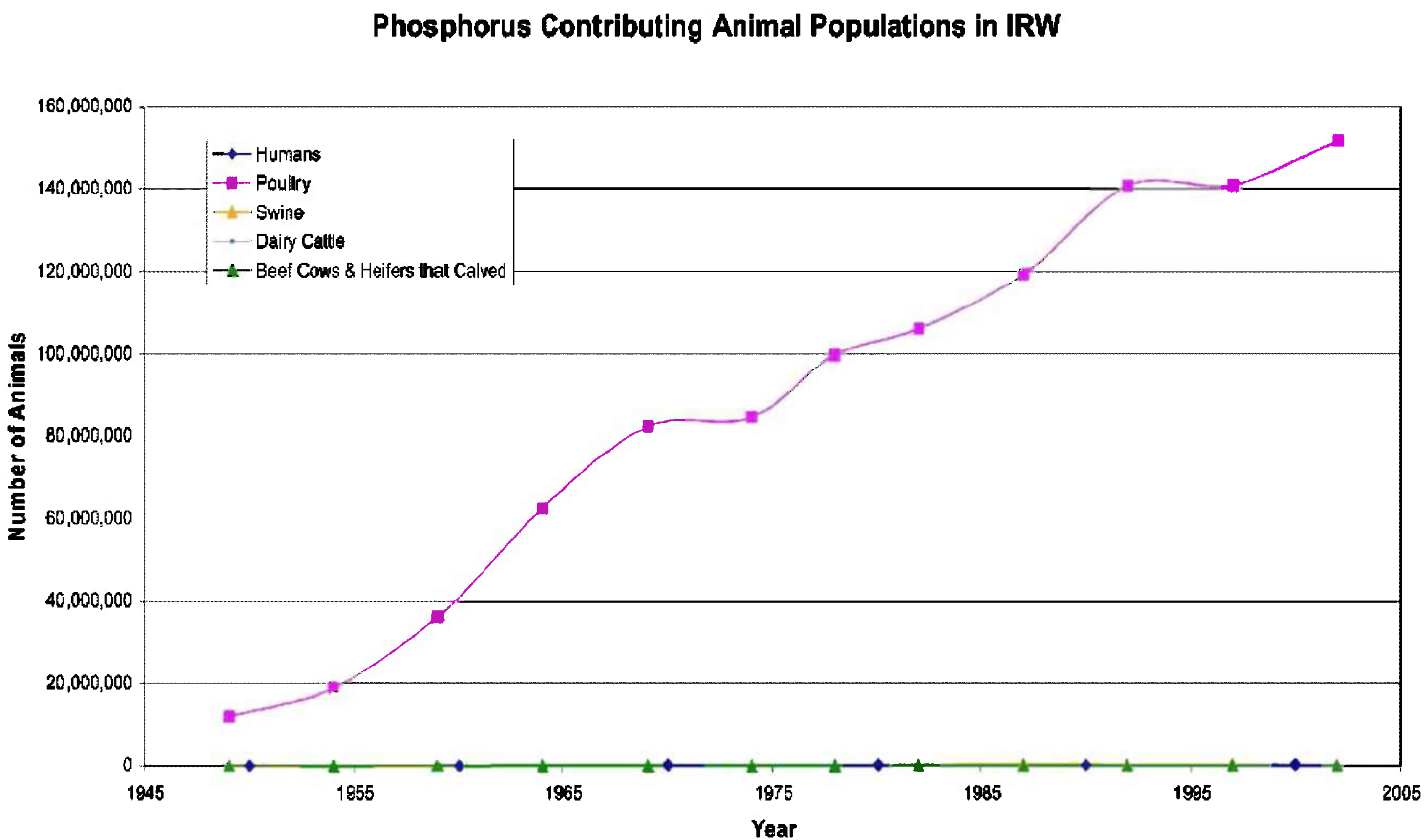

Figure 2. Annual phosphorus contributing animal populations in the IRW

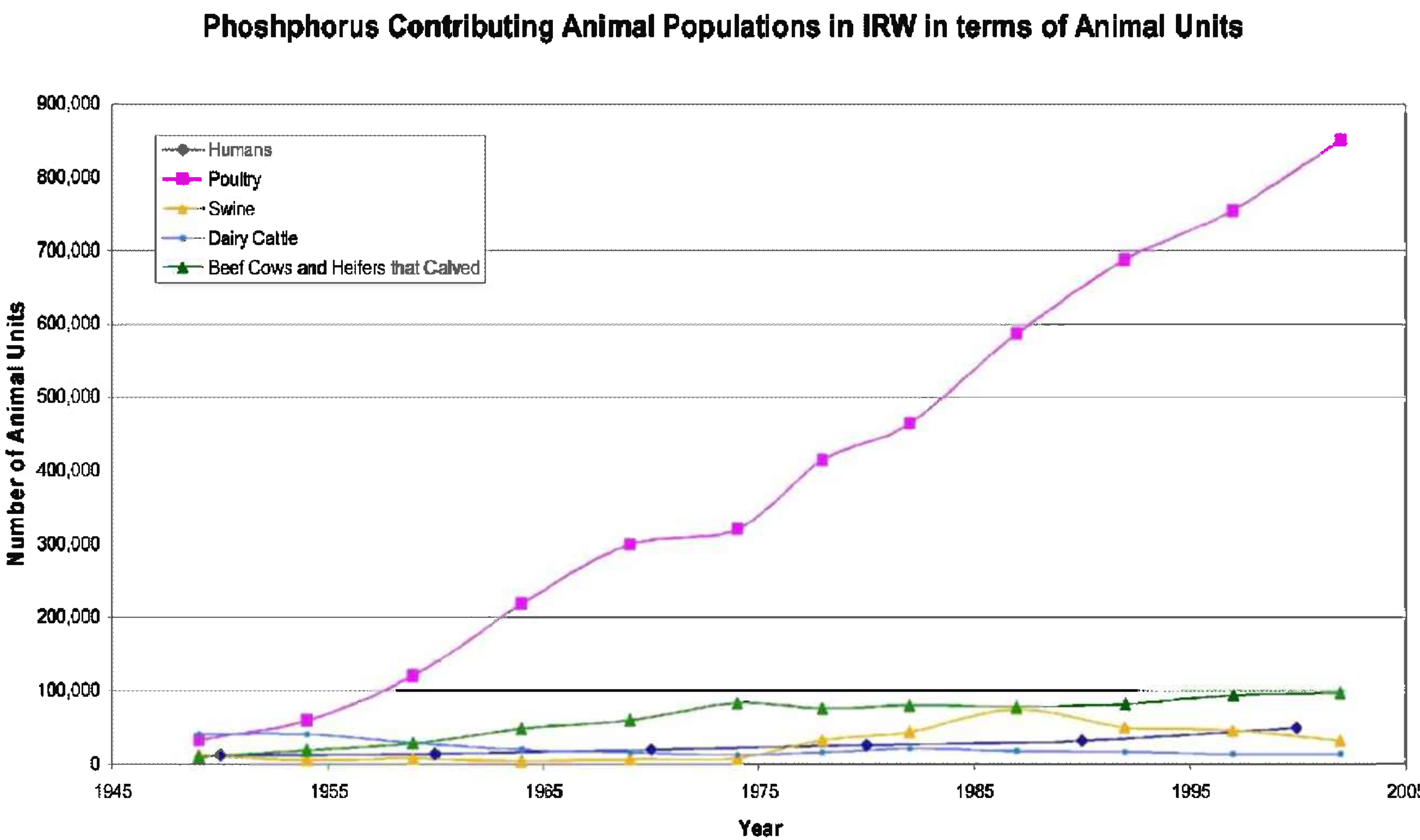

Figure 3. Annual phosphorus contributing animal populations in terms of animal units - 1000 lb. liveweight

4.2.2.1 Poultry

Four phosphorus generation rates were identified to calculate and compare the phosphorus additions attributable to the different poultry populations in the watershed. The four resources include:

- Agricultural Waste Management Field Handbook (USDA, 1992)
- ASAE Standard D384.2 MAR2005 (ASAE, 2005)
- Manure Characteristics – MWPS-18 Section 1 (MWPS, 2000)
- Data summarized from 321 Nutrient Management Plans (NMPs) from the Eucha/Spavinaw Watershed in northeastern Oklahoma. Data was summarized by Lithochimeia, Inc. (NMP, 2007).

Table 7 lists the phosphorus generation rate parameters from each resource for broilers, layers, pullets, and turkeys.

Table 7. Phosphorus generation rate parameters for poultry

Phosphorus Generation Rate Parameters for Poultry[a]				
	USDA	ASAE	MWPS	NMP
Bird Type	lb/day/AU[b]	lb/finished animal	lb/day	% manure[c]
Broiler	0.34	0.035	0.0006	2.08%
Layer	0.275	0.402[e]	0.0012	2.65%
Pullet[c]	0.24	NA	NA	1.78%
Turkey	0.4	0.26	0.0048	2.22%

[a]These rates are not directly comparable.
[b]Animal unit – 1000 lbs animal liveweight.
[c]As excreted manure values used for USDA. Values not available for ASAE or MWPS.
[d]Manure must be determined on dry basis.
[e]Converted from lb/day/animal

USDA

The USDA method of calculating phosphorus contributions allows one to explicitly account for the increase over time in the liveweights at market of broilers and turkeys. This is due to the phosphorus generation numbers being given in terms of animal units (AUs), defined as 1000 lb of animal. The liveweights at market for broilers and turkeys were taken from the Poultry Yearbook (ERS, 2006) for years 1964 through 2002. Prior to 1964, the liveweights were estimated using a linear regression. Table 6 lists the liveweights at market used for broilers and turkeys. The liveweights for layers and pullets were considered to be constant over time for these calculations. Layers were assumed to have a liveweight of 4lb (ASAE, 2005) and pullets were assumed to have an average liveweight of 2 lb. When calculating the phosphorus contributions, the liveweights for broilers and turkeys were assumed to be half the listed weight in order to account for the varying ages of animals on hand.

The growth cycles used for the USDA calculations were taken from ASAE Standard D384.2 MAR2005 (ASAE, 2005) for broilers and turkeys, and were assumed to be 48 days and 119 days, respectively. It was assumed layers are on the farm year round; therefore their growth cycle is 365 days. The growth cycle for pullets was assumed to be 20 weeks or 140 days (Ag Census, 2002). Table 8 lists the annual phosphorus additions for each bird type using the USDA resource for phosphorus generation rates.

Table 8. Annual phosphorus additions to the IRW from poultry using USDA (1992)

Annual Phosphorus Additions from Poultry - USDA - tons					
Year	Broilers	Layers	Pullets	Turkeys	All Poultry
1949	134	*	*	6	140
1954	225	*	*	53	278
1959	462	*	*	92	554
1964	862	353	*	*	1,215
1969	1,112	1,343	*	*	2,455
1974	1,246	779	*	*	2,025
1978	1,379	1,277	102	514	3,271
1982	1,511	1,552	100	663	3,825
1987	1,756	1,884	110	1,316	5,066
1992	2,292	1,516	113	1,037	4,958
1997	2,488	1,184	88	1,363	5,123
2002	2,924	978	80	1,281	5,263

*Population data not available

ASAE

ASAE Standard D384.2 MAR2005 (ASAE, 2005) lists phosphorus generation rates in terms of lb phosphorus/finished animal for broilers and turkeys, and lb phosphorus/day/animal for layers. Because these units do not account for the weight of the animal in the calculation, the phosphorus generation rates were converted to lb phosphorus/lb bird for each bird type using the average bird weights listed in the ASAE document for broilers and turkeys, and the average weight of a layer listed in ASAE Standard D384.1 FEB2003 combined with a 365 day growth cycle for layers. This reference does not provide nutrient generation rates for pullets, therefore phosphorus additions due to pullets was not be calculated under this method.

Annual phosphorus contributions were then calculated using the liveweights at market for broilers and turkeys found in Table 6 and the average liveweight for a layer of 4 lb (ASAE, 2003). Table 9 lists the annual phosphorus contributions from broilers, layers, and turkeys using the ASAE resource for phosphorus generation rates.

Table 9. Annual phosphorus additions to the IRW from poultry using ASAE (2005)

Annual Phosphorus Additions from Poultry - ASAE - tons				
Year	Broilers	Layers	Turkeys	All Poultry
1949	111	*	3	113
1954	186	*	24	210
1959	381	*	41	423
1964	712	353	*	1,065
1969	919	1,343	*	2,262
1974	1,030	779	*	1,809
1978	1,139	1,277	229	2,645
1982	1,248	1,552	296	3,096
1987	1,451	1,884	587	3,922
1992	1,894	1,516	462	3,872
1997	2,056	1,184	608	3,848
2002	2,416	978	571	3,966

*Population data not available.

MWPS

Manure Characteristics – MWPS-18 Section 1 (MWPS, 2000) lists phosphorus generation rates for broilers, layers, and turkeys in units of lb phosphorus/day. Phosphorus generation rates for pullets were not listed and therefore not calculated under this method. These units were converted to lb phosphorus/lb bird by using the bird weights listed combined with the average growth cycles used in previous calculations. The weights used were 4 lb for broilers (assuming the listed weight of 2 lb is the average weight during its growth cycle), 4 lb for layers, and 20 lb for turkeys. The phosphorus generation rates in lb phosphorus/lb bird were then applied to the historical average liveweight values for broilers and turkeys found in Table 6. Table 10 lists the annual phosphorus contributions from broilers, layers, and turkeys using the MWPS resource for phosphorus generation rates.

Table 10. Annual phosphorus additions to the IRW from poultry using MWPS (2000)

Annual Phosphorus Additions from Poultry - MWPS - tons				
Year	Broilers	Layers	Turkeys	All Poultry
1949	121	*	7	129
1954	204	*	63	267
1959	418	*	109	528
1964	780	382	*	1,162
1969	1,007	1,450	*	2,457
1974	1,129	841	*	1,970
1978	1,249	1,379	611	3,238
1982	1,368	1,676	788	3,833
1987	1,591	2,035	1,563	5,189
1992	2,076	1,637	1,232	4,945
1997	2,254	1,278	1,619	5,152
2002	2,649	1,056	1,522	5,227

*Population data not available.

NMP

Data from 321 Eucha/Spavinaw watershed Nutrient Management Plans (NMPs) was summarized by Lithochimeia, Inc. (NMP, 2007). The summarization culminated in as-is average waste generation rates in lb/finished bird, average moisture contents, average % total nitrogen and average % total phosphorus on a dry basis, and average bird weights at market. Note that the waste generation rates summarized from the NMPs are based on bird capacity and not number of birds produced. Because the capacity of a house is typically greater than the number of birds generated from the house, the per bird waste generation rates are underestimated. This will, in turn, underestimate the amount of phosphorus contributed to the watershed.

In order to account for the increase in bird weight over time, the waste generation rates were converted to lb waste/lb bird on a dry basis, using the average bird weights at market listed in the NMPs: 5.5 lb for broilers, 8 lb for layers, 8 lb for pullets, and 14 lb for turkeys. Because the average bird weights at market for layers, pullets, and turkeys differed so greatly from the other calculation methods, their phosphorus contributions were calculated using a constant weight over time, the average weight at market listed in the NMPs. The lb waste/lb bird generation rate for broilers was applied to the historical liveweights listed in Table 6. The % phosphorus for each bird type was then applied to the tonnage of waste produced by the corresponding bird type. Table 11 lists the annual phosphorus contributions from each bird type using the data summarized from the NMPs.

Table 11. Annual phosphorus additions to the IRW from poultry using NMP (2007)

Annual Phosphorus Additions from Poultry - NMP - tons					
Year	Broilers	Layers	Pullets	Turkeys	All Poultry
1949	140	*	*	2	142
1954	235	*	*	18	253
1959	482	*	*	29	511
1964	899	417	*	*	1,315
1969	1,160	1,583	*	*	2,743
1974	1,300	919	*	*	2,218
1978	1,438	1,505	249	137	3,329
1982	1,576	1,830	243	174	3,823
1987	1,832	2,222	268	328	4,649
1992	2,391	1,787	275	242	4,696
1997	2,596	1,396	216	288	4,495
2002	3,051	1,153	196	242	4,642

*Population data not available.

After reviewing the methods of calculating phosphorus additions from the various poultry populations in the IRW, it was determined the most accurate method is based on the summarized Nutrient Management Plans (NMPs) for the Eucha/Spavinaw watershed. This decision takes into account various factors regarding the data, including the proximity of the Illinois River Watershed and the Eucha/Spavinaw Watershed. This proximity of location results in comparable production methods between the two watersheds. The NMP data is very recent data with the bulk of all lab tests performed at the same lab, the Agricultural Diagnostic Laboratory at the University of Arkansas in Fayetteville. This results in highly consistent, reliable data. The NMP data also provides waste and phosphorus generation rates for pullets, which two of the other sources do not. Having generation numbers for pullets allows for the calculation of the overall phosphorus contribution from the entire poultry population in the watershed. The annual phosphorus additions from poultry using NMP (2007) data are depicted graphically in Figure 4.

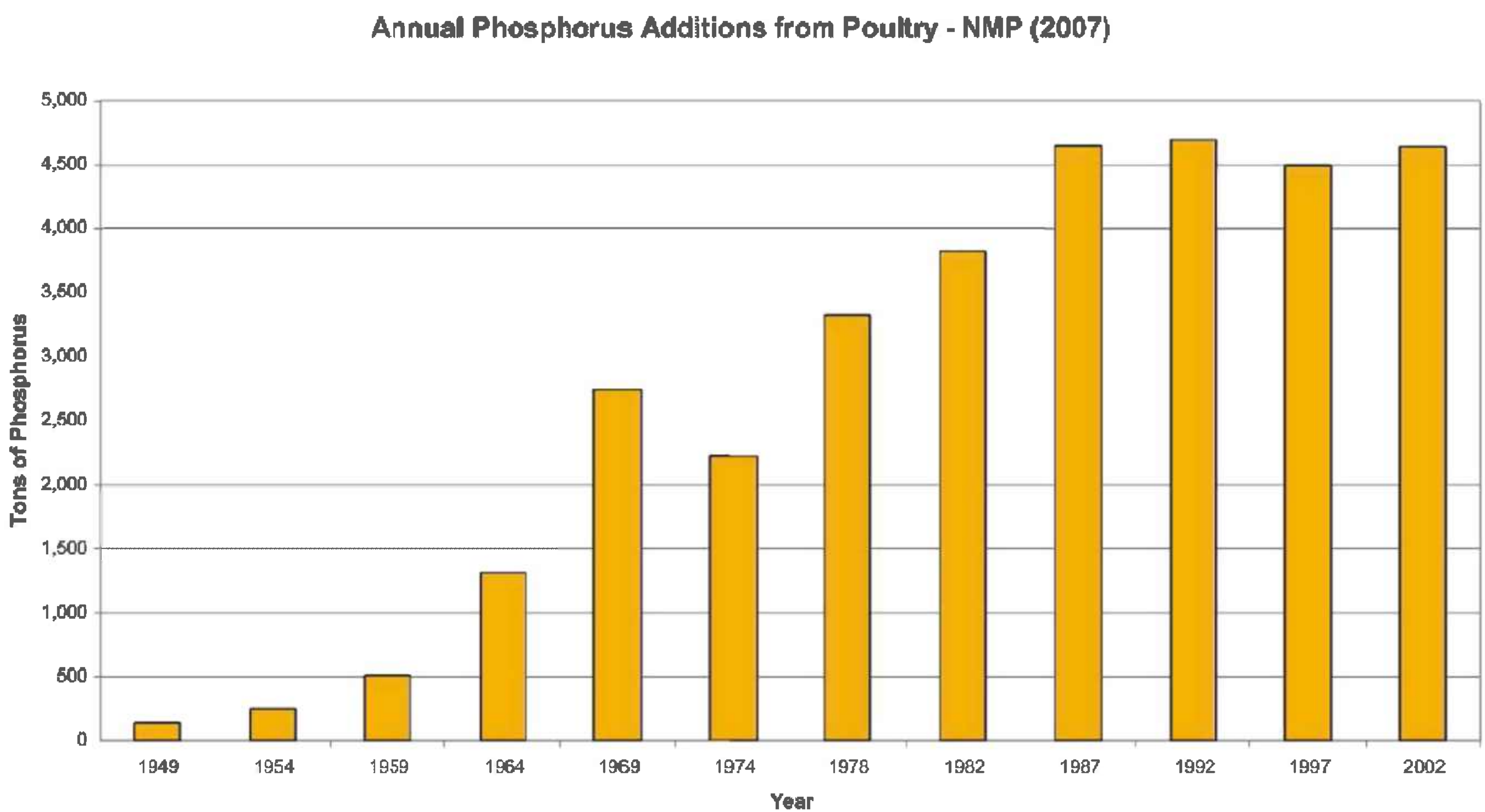

Figure 4. Annual phosphorus additions (tons) to the IRW from poultry

4.2.2.2 Swine and Dairy Cattle

Two resources for phosphorus generation rates were identified to calculate and compare the phosphorus contributions attributable to the swine and dairy cattle populations in the watershed: the Agricultural Waste Management Field Handbook (USDA, 1992) and ASAE Standard D384.2 MAR2005 (ASAE, 2005). Table 12 lists the phosphorus generation rates used in the calculations.

Table 12. Phosphorus generation rates for swine and dairy cattle

Phosphorus Generation Rate Parameters for Swine and Dairy Cattle[a]		
	USDA	**ASAE**
Animal Type	lb/day/AU[b]	lb/finished animal
Swine	0.16	1.7
Dairy Cattle	0.07	62[c]

[a]These rates are not directly comparable.
[b] Animal Units – 1000 lb animal liveweight.
[c]Converted from lb/day/animal

In order to calculate the overall phosphorus contributions attributable to the swine and dairy cattle populations using the USDA method, average animal liveweights and growth cycles were needed. The liveweight used for swine was 155 pounds with all swine in the watershed assumed to be grower/finishers with a growth cycle of 120 days (ASAE, 2005). The liveweight used for dairy cattle was 1375 pounds (ASAE, 2005) with all dairy cattle assumed to be full-grown and lactating and on farm year round, yielding a growth cycle of 365 days.

Calculating the overall phosphorus contributions using the ASAE method required first converting the phosphorus generation rate for dairy cattle from lb/day/animal to lb/finished animal using the growth cycle of 365 days. The phosphorus generation rates were then applied to the number of swine and dairy cattle in the watershed. The annual phosphorus contributions for swine and dairy cattle using both methods are listed in Table 13.

Table 13. Annual phosphorus additions to the IRW from swine and dairy cattle (USDA, 1992 and ASAE, 2005)

Annual Phosphorus Additions from Swine and Dairy Cattle - tons				
	USDA		ASAE	
Year	Swine	Dairy Cattle	Swine	Dairy Cattle
1949	118	518	68	915
1954	57	525	33	927
1959	76	373	43	659
1964	42	261	24	462
1969	66	205	38	362
1974	85	163	49	289
1978	317	207	181	365
1982	423	274	242	485
1987	721	230	412	406
1992	483	213	276	377
1997	445	175	254	309
2002	310	181	177	319

For comparing phosphorus contributions from swine and dairy cattle to all sources in the watershed, the ASAE Standard D384.2 MAR2005 was because it had the most recent data.

4.2.2.3 Beef Cows and Heifers that Calved

Beef cattle in the watershed are grazing animals that recycle phosphorus already in the landscape (Slaton et al., 2004 and Lalman, 2004). It was noted, however, that the implementation of a high protein supplement schedule for beef cows and heifers that calve can be beneficial to cow health (Gill and Lusby, 2003). In order to account for phosphorus additions resulting from possible protein supplementation, it was assumed all beef cows and heifers that calved in the watershed are on a winter supplementation schedule. Common supplementation strategies were taken from Supplementing Beef Cows (Lalman, 2004) and can be found in Table 14.

Table 14. Daily high protein supplementation schedule

Daily Supplementation Schedule		
Month	Spring Calving Cows	Fall Calving Cows
October	None	1 lb HP
November	1 lb HP*	2 lb HP
December	2 lb HP	3 lb HP
January	3 lb HP	3 lb HP
February	3 lb HP	3 lb HP
March	3 lb HP	3 lb HP
April	2 lb HP	2 lb HP

*HP = high protein supplement, such as 38% protein range cubes or cottonseed meal.

In order to calculate the overall phosphorus additions, the supplementation schedule includes using 41% cottonseed meal as the supplement and a 50% spring calving, 50% fall calving rate (Lalman, D., personal communication, 4 April 2008). It was also assumed the cows were in good body condition and winter weather was moderate. Note that cottonseed meal has a phosphorus content of 1.25%, the highest phosphorus content of all commonly used supplements and feeds (Lalman, 2004).

The pounds of supplement were summed for both spring and fall calving schedules and multiplied by the number of spring and fall calving cows in the watershed. The annual phosphorus contributions due to cottonseed meal supplementation are found in Table 15.

Table 15. Annual phosphorus additions to the IRW from beef cows and heifers that calved

Annual Phosphorus Additions from Beef Cows & Heifers that Calved	
Year	Tons P
1949	30
1954	58
1959	87
1964	148
1969	182
1974	254
1978	231
1982	243
1987	238
1992	250
1997	285
2002	296

4.2.3 Commercial Fertilizer

The phosphorus contributions from commercial fertilizer applications were quantified using the conservative assumption that all commercial fertilizer sold within the watershed was applied to crop and pasture acreage within the watershed.

Available fertilizer sales data was gathered from the Oklahoma Department of Agriculture and the Arkansas State Plant Board. State fertilizer sales data and fertilizer sales data for the counties in the IRW were used to project fertilizer sales spanning from 1951 to 2002 (G. Johnson, Appendix A). All fertilizer phosphorus values were reported in P_2O_5 and converted to total P using: Total P = P_2O_5 * 0.44. The projected county fertilizer sales were then multiplied by the percentage of crop and pasture acreage inside the IRW for each county. Table 16 shows total phosphorus sales for the Oklahoma and Arkansas portions of the IRW, as well as the totals for the entire watershed.

Table 16. Annual phosphorus additions to the IRW based on projected commercial fertilizer sales for the IRW in Oklahoma and Arkansas

Annual Phosphorus Additions from Commercial Fertilizer Sales in IRW - tons			
Year	Oklahoma	Arkansas	IRW
1951	253	8	261
1954	258	23	281
1959	253	49	302
1964	221	74	296
1969	189	100	289
1974	167	125	293
1978	187	146	333
1982	176	166	342
1987	178	192	369
1992	198	311	509
1997	197	248	446
2002	200	256	455

4.2.4 Golf Courses

The next step in determining the overall mass balance for phosphorus in the IRW was to consider the phosphorus addition from golf courses located in the watershed. The use of commercial fertilizers is standard practice for golf course superintendents around the country, and it is no exception for the seven 9-hole courses and thirteen 18-hole courses located within the IRW (South Central Golf Magazine and www.golfcourseportal.com). A list of all golf courses in the IRW can be found in Appendix B.

For the following calculations, it was assumed the vast majority of fertilizer for golf courses is applied to the fairways with the 18-hole courses in the watershed having average fairway acreages of 32 acres and the 9-hole courses being half that acreage, or 17.5 acres (EPA, 2007).

The amount of applied phosphorus was compared using two methods. The first method employed the following fertilizer regimen (G. Hallett, personal communication, 7 August 2006):

- May – 1 lb N/1000 ft^2 in the form of ammonia sulfate (20.5-0-0)
- June – 1 lb N/1000 ft^2 in the form of slow release fertilizer (39-0-0)
- August – 1 lb N/1000 ft^2 in the form of slow release fertilizer (39-0-0)
- September – 0.5 lb N/1000 ft^2 in the form of (5-10-31)

The second method used for calculating the amount of applied phosphorus to golf courses in the watershed was extrapolated from Martin and Hillock (2002). Martin and Hillock (2002) recommends a moderate fertilization program for Bermuda grass using the following regimen:

- May – 1 lb N/1000 ft^2 in the form of (15-5-10)
- July – 1 lb N/1000 ft^2 in the form of (20.5-0-0)
- September – 1 lb N/1000 ft^2 in the form of (15-5-10)

The tonnage of annually applied phosphorus using both methods is compared in Table 17 The results vary between the two methods, but when compared to the phosphorus additions from other sources in the watershed, either method results in a negligible amount of phosphorus from golf course fertilizer application. As such, the conservative approach of assuming the current addition of phosphorus to be constant over time was used in order to compare against other historical phosphorus additions.

Table 17. Annual phosphorus additions from golf courses in the IRW

Annual Phosphorus Additions from Golf Courses	
Calculation Method	Tons Phosphorus
Method 1	5.1
Method 2	3.4
Average	4.2

4.2.5 Urban Runoff

Another consideration in determining the overall phosphorus mass balance for the IRW concerns the phosphorus additions attributable to urban storm water runoff. Phosphorus sources for urban runoff include residential fertilizer applications and domestic pet waste. The first step in determining this addition was to establish the developed acreage in the watershed. This was done using the NLCD 2001. As seen in Table 1, there are 92,189 acres of developed land in the watershed. Combining this developed land area with urban runoff phosphorus concentrations from the National Stormwater Quality Database: Version 1.1 (Pitt et al., 2004) of 0.27 mg Total P/L and an average annual runoff for urban areas in the region of 10 inches, estimated using the Long-Term Hydraulic Assessment model (L-THIA, www.ecn.purdue.edu/runoff/lthianew/Index.html), yielded the phosphorus additions to the watershed from the developed areas.

In order to calculate historical values for phosphorus additions from urban runoff, it was first assumed that the amount of developed land using the NLCD 2001 data corresponded with the urban population from the 2000 U.S. Census. From there, a linear correlation was assumed between the acreage of developed land in the watershed and the urban population, allowing the determination of historical urban runoff phosphorus values to be calculated based on historical U.S. Census urban populations for the watershed. The results of the phosphorus calculations are listed in Table 18.

Table 18. Annual phosphorus additions to the IRW from urban runoff

Annual Phosphorus Additions from Urban Runoff	
Year	Tons Phosphorus
1950	8.4
1960	9.2
1970	12.6
1980	16.7
1990	19.4
2000	28.2

4.2.6 Wholesale Nurseries

Another potential source of phosphorus to the IRW is the large-scale plant nurseries in the IRW. The first step in calculating the phosphorus contributions was to determine the number and size of all wholesale plant nurseries in the basin. This was done using the Oklahoma Nursery & Landscape Association (ONLA) website and the Arkansas Green Industry Association (ARGIA) website. It was determined there are three wholesale nurseries in the basin, all of which are located in or near Tahlequah, Oklahoma. The nurseries vary in size with Grandview Nursery Co., Inc. being the smallest at approximately 250 acres, Park Hill Wholesale Nursery is next at approximately 500 acres, and Greenleaf Nursery Co., Inc is the largest at 570 acres.

Using a similar calculation method as used for urban runoff, the phosphorus additions from plant nurseries were quantified using average nursery tailwater concentrations for total phosphate taken from the Curtis Report (ODA, 1993) combined with average annual runoff for eastern Oklahoma of 20 inches from the Oklahoma Water Atlas (OWRB, 1990) and nursery land areas. The average tailwater concentration for phosphorus in the Curtis Report was 1 mg P_2O_5/L. This value translates to 0.44 mg total P/L. The resulting current phosphorus addition due to wholesale plant nurseries in the IRW is 1.3 tons phosphorus/year (Table 19). Note this is a conservative estimate of the phosphorus addition from plant nurseries due to the fact that at least one nursery in the watershed is equipped with total retention technology (Alexander, 1999). As such, the conservative approach of assuming the current addition of phosphorus to be constant over time was used in order to compare against other historical phosphorus additions.

Table 19. Annual phosphorus addition to the IRW from wholesale plant nurseries

Phosphorus Addition - Wholesale Nurseries
1.3 tons/yr

4.2.7 Recreational Users

The phosphorus contribution attributable to annual recreational users in the IRW was determined based on annual recreational visits to the watershed combined with phosphorus generation rates for humans. Recreational users include not only those visitors who float or canoe on the River, but also those using the banks of the River for recreational purposes and those using Lake Tenkiller and the immediate surrounding scenic area. Illinois River and Lake Tenkiller recreational user numbers were taken from Caneday (2008). Dr. Caneday lists user numbers on the Illinois River as 155,555 per year and user numbers at Lake Tenkiller as 2,617,359 per year. The River numbers include both river floaters and non-floaters and the Lake numbers include campers, day visitors, and boaters. It is conservatively assumed that all recreational users originate from outside the watershed.

The phosphorus contributions were then calculated using the Agricultural Waste Field Handbook (USDA, 1992). The phosphorus addition due to recreational users is 4.9 tons phosphorus/year (Table 20). In order to compare the phosphorus addition from recreational users to other historical sources of phosphorus in the IRW, it was conservatively assumed the current addition of phosphorus has been constant over time.

Table 20. Annual phosphorus addition to the IRW from recreational users

Annual Phosphorus Addition Recreational Users	
Population	Tons Phosphorus
2,772,914	4.93

4.2.8 Industrial Sources

Information provided by Dr. Engel (personal communication, 10 April 2008) lists all known industrial facilities in the IRW, with a facility description, and their average daily phosphorus additions. This information is provided in Appendix C. There are thirteen companies listed with a total of 23 facilities. Inputs regarding the now closed Stilwell Cannery were not available; therefore the calculated totals do not reflect additions from this source.

The values provided were translated to average annual phosphorus additions in tons/year and are summarized to poultry and non-poultry related facilities in Table 21. Of the 162.6 tons phosphorus/year attributable to industrial sources, only 18% or 29 tons of phosphorus, comes from non-poultry related facilities. These non-poultry related facilities include Allen Canning Co., Cintas Corporation, Danaher Tool Group, J.B. Hunt Transport, Inc., Pappas Foods, L.L.C., Superior Linen Service, and Tyson Foods, Inc. – Hog Trailer Wash. The remaining 133.6 tons of phosphorus comes from egg and poultry processing facilities in the IRW. In order to account for the historical phosphorus additions from industrial sources, the current addition is used for all historical comparisons to other phosphorus sources.

Table 21. Current annual phosphorus contribution, in tons, from industrial sources in the IRW.

Annual Phosphorus Contributions - Industrial Sources	
Facility Type	**Tons Phosphorus**
Poultry Related	133.6
Non-poultry Related	29
Total	162.6

Although the majority of phosphorus being introduced to the IRW from industrial sources is attributable to the poultry industry (82%), it is not being included as a phosphorus addition from poultry production.

4.3 Summary of Phosphorus Additions

Upon quantifying the phosphorus loads coming into the Illinois River Watershed, the loads from all sources were compared in order to determine the source(s) of the greatest contribution of phosphorus. Table 22 compares current phosphorus loads from each source as well as current phosphorus loads in terms of percentage of the current total addition.

Table 22. Comparison of current annual phosphorus loads to IRW listed in tons of phosphorus and % of current total phosphorus addition

Current Phosphorus Additions to IRW[a]		
Source	Tons P	% of Current P Addition
Humans	182	2.9%
Poultry	4,642	74.0%
Swine	177	2.8%
Dairy Cattle	319	5.1%
Heifers and Beef Cows that Calved	296	4.7%
Commercial Fertilizers	455	7.3%
Urban Runoff	28.2	0.4%
Industrial Sources[b]	163	2.6%
Other Additions[c]	10.5	0.2%
Total	6,273	100.0%

[a]Total phosphorus addition, without subtracting any source removals, i.e. beef cattle.
[b]Includes phosphorus additions from poultry processing facilities.
[c]Includes golf courses, wholesale nurseries, and recreational users.

4.4 Phosphorus Removals

Four phosphorus removals were identified for the IRW. They include the phosphorus removed by grazing beef cattle sold and removed from the watershed, crops harvested, deer harvested, and water leaving Tenkiller Ferry Reservoir through the spillway.

4.4.1 Beef Cattle

Beef cattle are the only livestock considered to remove phosphorus from the watershed. This is based on the assumption that all poultry, swine, and dairy cattle are given feed brought into the watershed and are not grazing animals, therefore the waste produced would introduce phosphorus to the watershed. All beef cattle in the watershed are primarily grazing animals, recycling the phosphorus in the watershed along with all other grazing livestock (Lalman, 2004 and Slaton, 2004). However, the number of beef cattle sold is significant enough to warrant accounting for the removal of phosphorus upon being sold and removed from the watershed. The difference between the addition of phosphorus from supplementation of beef cows and heifers that calved and the removal of phosphorus from beef cattle sold will determine whether there is a net loss or addition of phosphorus to the watershed from beef cattle.

The cattle population sold from the IRW was determined in the same manner as the previous livestock calculations. The number of beef cattle sold from each county within the watershed was gathered from the 1949 through 2002 U.S. Census of Agriculture. The number of cattle sold from within the IRW was then determined based on the percentage of pasture acreage for each county that lies inside the watershed boundary. Again, this method of cattle distribution is based on the assumption that cattle would not be housed or grazed on cropland, forests, or developed areas and would be equally distributed on pasture (Nelson et al., 2002). This process provided the historical and present number of beef cattle sold from the watershed.

The amount of phosphorus removed from the watershed was then determined based on ASAE Standard D384.2 (ASAE, 2005) and Smolen et al. (1994). For calculations performed by Smolen et al. (1994), assumptions included an average beef cattle weight gain of 500 lb per head with 20% of that being protein. Combining this average weight gain and make-up with the recognized average phosphorus retention of 3.9 g per 100 g of retained protein (ASAE, 2005), yields the amount of phosphorus sold out of the watershed with each head of cattle. The retention amounts are found in Table 23.

Table 23. Tons of phosphorus removed annually by beef cattle sold

Annual Phosphorus Removal by Beef Cattle Sold	
Year	Tons P
1949	60
1954	83
1959	89
1964	114
1969	157
1974	155
1978	191
1982	167
1987	182
1992	168
1997	192
2002	192

Comparing the addition of phosphorus due to protein supplementation of beef cows and heifers that calved with the removal of phosphorus due to beef cattle sold resulted in a net addition of phosphorus to the watershed beginning in 1964. These net additions are shown in Table 24.

Table 24. Net annual phosphorus additions due to beef cattle

Net Annual Phosphorus Addition - Beef Cattle	
Year	Tons P
1949	-
1954	-
1959	-
1964	33
1969	25
1974	98
1978	41
1982	76
1987	55
1992	81
1997	94
2002	105

4.4.2 Harvested Crops

Next, the removal of phosphorus from the IRW due to harvesting crops was calculated. The first step was to determine the major crops currently and historically harvested in the watershed and their overall production or yield rates. This was established by referring to the U.S Census of Agriculture (Ag Census, 1949-2002). After review, the crops with the greatest production in the watershed from 1964 to 2002 were determined to be corn, sorghum and wheat for grain, as well as soybeans for beans. For Ag Census years 1949, 1954, and 1959, oats for grain were also included for calculation purposes. Beginning with Ag Census year 1964, the production of oats for grain began a steep decline.

The removal of phosphorus due to forage crops was not included in these calculations. Although hay/forage crops are the major crop grown in the watershed, it was assumed all hay/forage crops harvested in the IRW remain in the IRW as feed for foraging livestock; therefore the phosphorus is being recycled, not removed from the watershed (Slaton et al., 2004 and Lalman, 2004).

The yield per acre was determined for each crop for each year for both the Oklahoma and Arkansas portions of the watershed. This was accomplished by summing the production of each crop, in either tons or bushels, and dividing by the number of acres under production for that crop (Ag Census, 1949-2002). The number of acres under production for each crop for each county was then multiplied by the percentage of cropland that actually lies within the watershed boundary for each county, resulting in the number of acres under production, for each crop, within the watershed boundary.

The yield per acre for each crop was used with the Crop Nutrient Tool on the Natural Resources Conservation Service website (NRCS; npk.nrcs.usda.gov) to determine the phosphorus removed by harvest in lb/acre. The results were then multiplied by the number of acres under production for each crop for each state. The final phosphorus removal results are found in Table 23. A detailed list of the amount of nutrients removed by each crop can be found in Appendix D.

Table 25. Tons of phosphorus removed annually by harvested crops

Annual Phosphorus Removal by Harvested Crops	
Year	Tons P
1949	74
1954	37
1959	43
1964	17
1969	14
1974	11
1978	19
1982	28
1987	15
1992	11
1997	12
2002	14

4.4.3 Deer

The phosphorus removed by deer harvested from the watershed during hunting season was quantified in order to determine its share of removal of phosphorus. The first step for these calculations was to determine the number of deer harvested from each of the counties within the IRW. This information was gathered for years 2001 to 2005 from the Oklahoma Department of Wildlife Conservation and years 2002-2003 through 2005-2006 from the Arkansas Game and Fish Commission. The harvest numbers for the two states are reported in different formats. For Oklahoma the numbers are reported on an annual basis and for Arkansas they are reported on a seasonal basis. Upon reviewing available harvest data, it was concluded the most appropriate harvest numbers to use were those from the most recent reporting year, 2005 for Oklahoma and 2005-2006 for Arkansas, and assume them constant over time if needed.

For this calculation, harvest densities were calculated using the pasture, crop, and forest acreage for each county within the watershed, yielding the number of deer harvested per acre The harvest density values were then multiplied to the pasture, crop, and forest acreages that lie within the boundary of the watershed for each county to determine the harvest numbers for the watershed. This resulted in a total of 3,982 deer harvested and removed from the IRW.

Once the deer harvest numbers were established, phosphorus removal values were determined based on literature values. Two assumptions were made in order to perform the necessary calculations: 1) all deer harvested were bucks with an average hog-dressed weight of 103 lb (Masters et al., 2004) and 2) all deer harvested were white-tail deer with a meat protein content of 23.6 g protein/100 g meat (UIUC, 2006). Using the recognized average phosphorus retention rate of 3.9 g of retained phosphorus per 100 g of retained protein (ASAE, 2005) yields a phosphorus removal of 1.9 tons phosphorus/year (Table 26). Because historical deer harvest values were not available, the current removal rate of phosphorus due to harvested deer in the watershed was assumed to remain constant over time in order to compare with other historical phosphorus removals.

Table 26. Tons of phosphorus removed annually from the IRW by harvested deer

Annual Phosphorus Removal by Harvested Deer	
Year	Tons Phosphorus
2005	1.9

4.4.4 Lake Tenkiller Spillway

The dam located at the south end of Lake Tenkiller has an average annual release of 236 billion gallons (Dr. Engel, personal communication, 10 April 2008). Due to the lake acting as a catch basin for phosphorus, the phosphorus in the water column is removed from the watershed as water is released through the spillway. As determined by Dr. Engel, the average phosphorus outflow through the spillway is 75 tons P/year (Table 27) (Dr. Engel, personal communication, 10 April 2008). Given that historical phosphorus data for the spillway is unavailable, the current removal of phosphorus through the spillway was assumed to be constant over time in order to compare with other historical removals.

Table 27. Tons of phosphorus removed from the IRW by the spillway on Lake Tenkiller

Phosphorus Removal - Lake Tenkiller Spillway
75 tons/yr

4.5 Summary of Phosphorus Removals

Upon quantifying the total mass of phosphorus leaving the Illinois River Watershed, the values were compared in order to determine the greatest removal of phosphorus. Table 28 compares the current removals of phosphorus from the IRW. Note it was determined the flow of phosphorus in the watershed due to beef cattle resulted in a net addition of phosphorus.

Table 28. Comparison of current annual phosphorus removals from the IRW

Current Phosphorus Removals from IRW	
Source	Tons P
Spillway	75
Harvested Crops	14
Deer	1.9
Total	91.2

The total current phosphorus removals from the IRW remove 1.5% of the current phosphorus additions to the IRW.

4.6 Overall Net Addition of Phosphorus

The net addition of phosphorus in the Illinois River Watershed from 1949 to 2002 was determined using linear interpolation where needed. Data that did not have corresponding years with the Ag Census (additions due to human population and urban runoff) were linearly interpolated to account for those years. Table 29 lists the annual phosphorus additions from all sources to the IRW for the Ag Census years from 1949 to 2002. Table 30 lists the annual phosphorus removals from the IRW for the Ag Census years from 1949 to 2002. The net additions and removals for the interim years without data were then determined using linear interpolation. From 1949 to 2002, there was more than 219,000 tons of phosphorus added to the IRW. Almost 68% of that addition, more than 148,000 tons, was attributable to poultry production. There was an overall net addition from 1949 to 2002 of nearly 214,000 tons of phosphorus to the IRW.

Table 29. Annual phosphorus additions, in tons, to the Illinois River Watershed. Includes the percentage of the total addition from poultry.

Phosphorus Additions by Source for the IRW - tons											
Year	Human	Poultry	Swine	Dairy Cattle	Beef Cattle[a]	Commercial Fertilizer	Urban Runoff	Industrial Sources[b]	All Other Additions[c]	Total	% from Poultry
1949	44	142	68	915	-	261	8	163	10.5	1,611	9%
1954	47	253	33	927	-	281	9	163	10.5	1,723	15%
1959	51	511	43	659	-	302	9	163	10.5	1,748	29%
1964	60	1,315	24	462	33	296	11	163	10.5	2,374	55%
1969	71	2,743	38	362	25	289	11	163	10.5	3,712	74%
1974	82	2,218	49	289	98	293	14	163	10.5	3,216	69%
1978	92	3,329	181	365	41	333	16	163	10.5	4,529	74%
1982	101	3,823	242	485	76	342	17	163	10.5	5,259	73%
1987	112	4,649	412	406	55	369	19	163	10.5	6,196	75%
1992	131	4,696	276	377	81	509	21	163	10.5	6,264	75%
1997	163	4,495	254	309	94	446	26	163	10.5	5,959	75%
2002	195	4,642	177	319	105	455	30	163	10.5	6,095	76%

[a]Phosphorus addition from beef cows and heifers that calved minus removal from beef cattle sold.
[b]Includes poultry processing facilities
[c]Includes golf courses, wholesale nurseries, and recreational users.

Table 30. Annual phosphorus removals for the Illinois River Watershed.

Phosphorus Removals - tons				
Year	Spillway	Harvested Crops	Harvested Deer	Total
1949	75	74	1.89	151
1954	75	37	1.89	114
1959	75	43	1.89	119
1964	75	17	1.89	93
1969	75	14	1.89	91
1974	75	11	1.89	88
1978	75	19	1.89	96
1982	75	28	1.89	104
1987	75	15	1.89	92
1992	75	11	1.89	88
1997	75	12	1.89	88
2002	75	14	1.89	91

4.7 Summary of Findings

Figure 5 illustrates the current phosphorus additions and removals, in tons, to the Illinois River Watershed. This figure demonstrates there is more phosphorus coming into the IRW than is being removed, with poultry production being responsible for a large majority of the phosphorus addition (> 76%).

Figure 6 illustrates the current and historical phosphorus additions to and removals from the IRW. This figure demonstrates that for decades, the addition of phosphorus to the watershed has been greater than the removal of phosphorus. This results in an accumulation of phosphorus over time. It can be seen from this figure that poultry production has been by far the greatest contributor of phosphorus to the IRW since, at the very latest, 1964.

Figure 7 illustrates the current percentage of phosphorus additions to the IRW by source. This figure demonstrates that poultry, by far, is the major contributor of phosphorus to the watershed, being responsible for more than 76% of the current phosphorus additions.

Figure 8 illustrates the current and historical percentages of the phosphorus additions in the IRW attributable to poultry. This figure demonstrates a drastic increase in the percent of phosphorus addition due to poultry from 1949 to 1969, from 9% to 74 % From 1974 to 2002 there has been a steady increase in the percentage of the overall phosphorus addition in the IRW due to poultry, from 69% to 76%. Note that over the past three decades, poultry production has consistently been responsible for approximately 75% of the total annual phosphorus additions to the watershed.

Figure 9 illustrates a comparison of the current and historical percentages of phosphorus additions in the IRW attributable to poultry and the percentage attributable to all other sources combined (humans, swine, dairy cattle, beef cattle, commercial fertilizer, urban runoff, industrial sources, golf courses, wholesale nurseries, and recreational users). This figure demonstrates that the percentage of the overall phosphorus additions in the IRW due to poultry has been increasing over time while the percentage of overall phosphorus additions in the IRW due to all other sources has been decreasing over time.

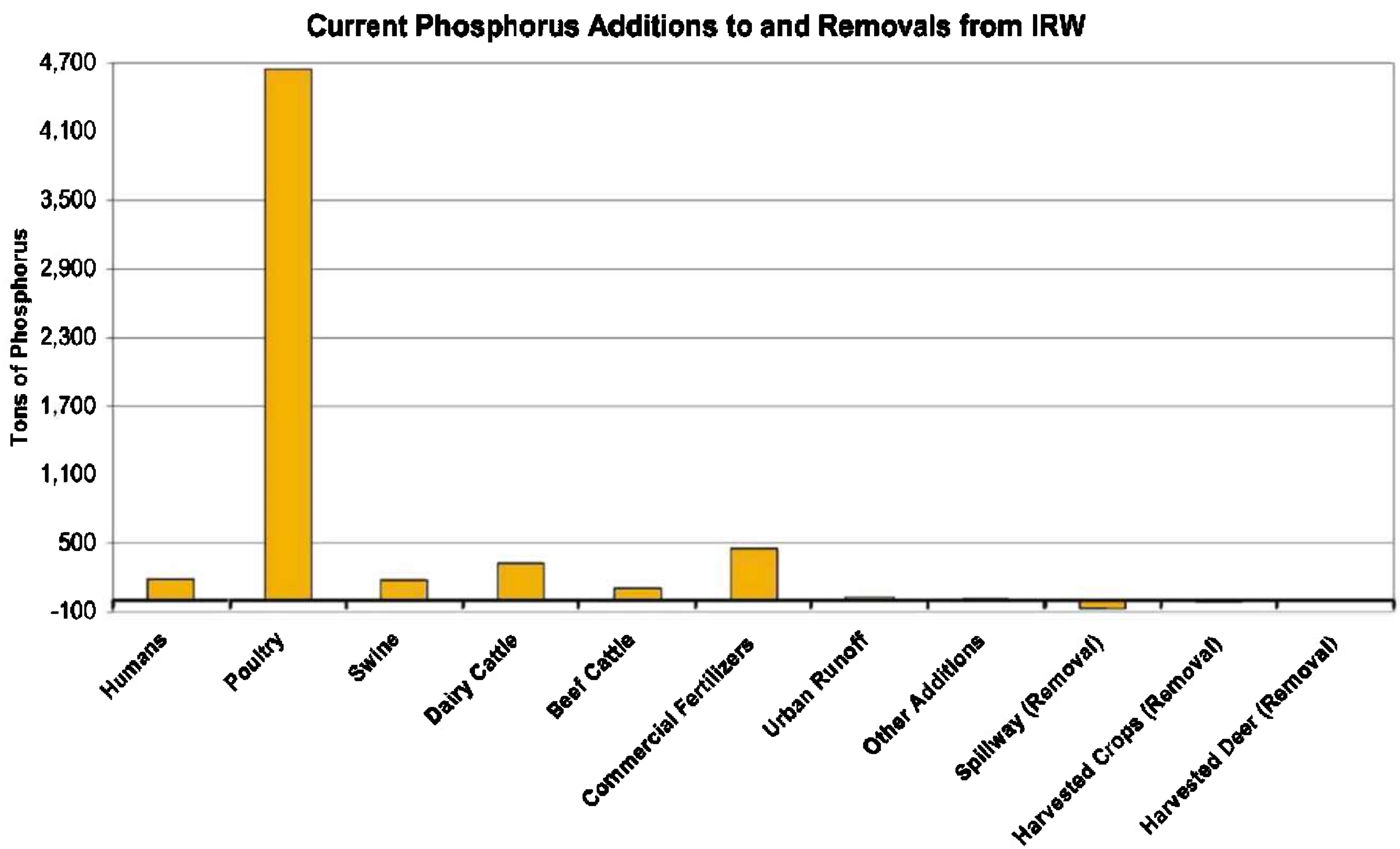

Figure 5. Current phosphorus additions to and removals from the Illinois River Watershed

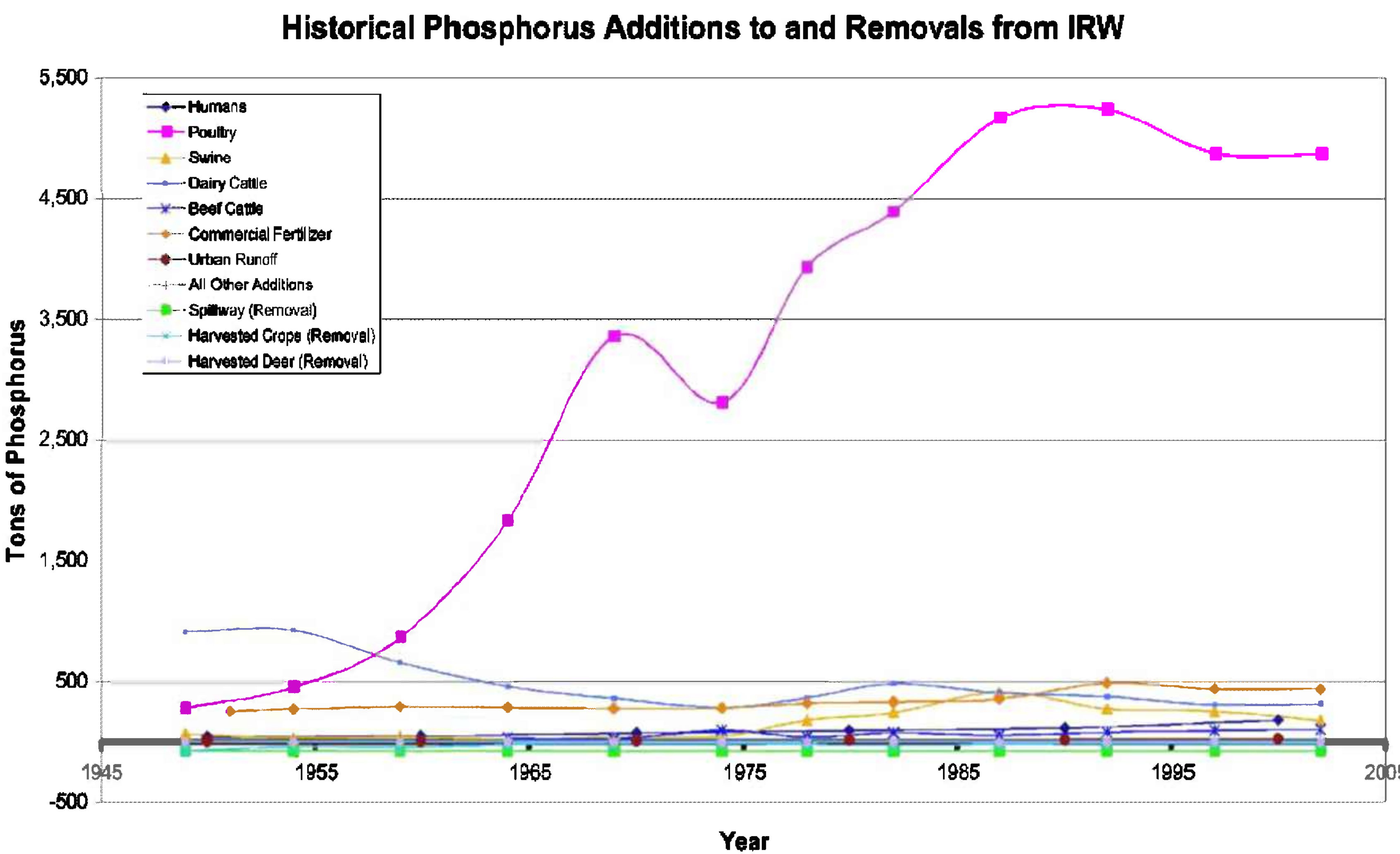

Figure 6. Historical phosphorus additions to and removals from the Illinois River Watershed

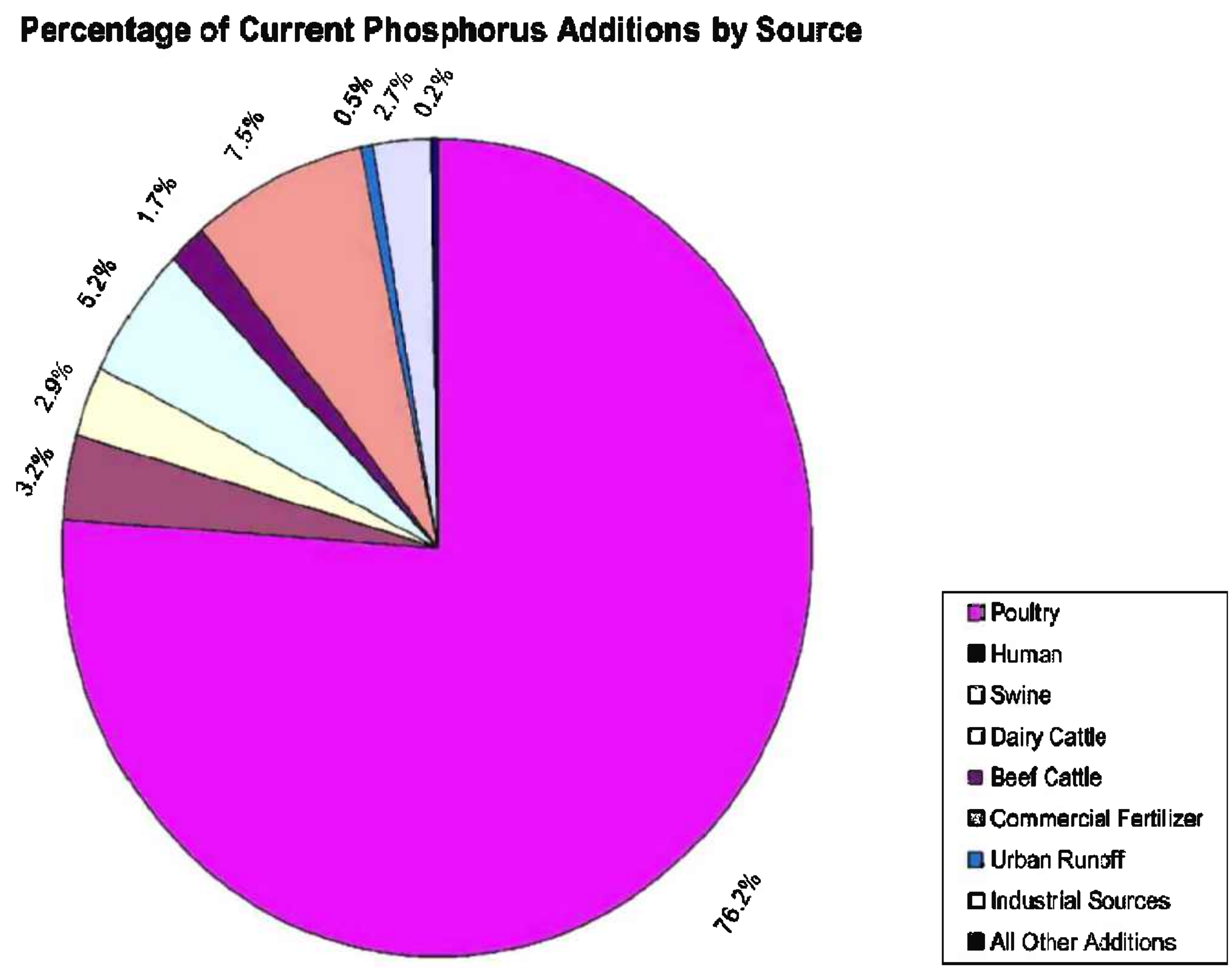

Figure 7. Percentage of current phosphorus additions to the IRW by source

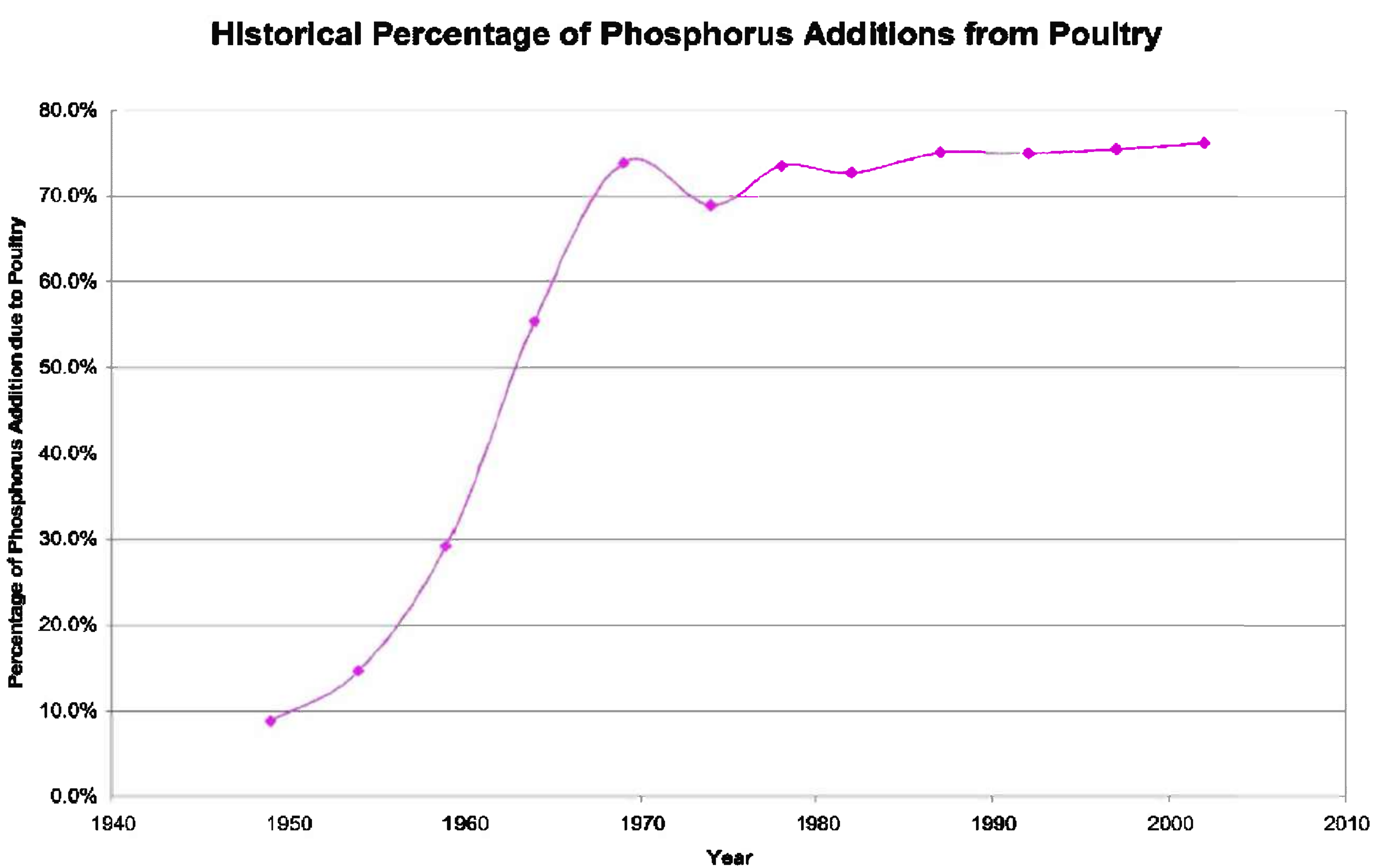

Figure 8. Historical percentage of phophorus additions to the IRW from poultry production

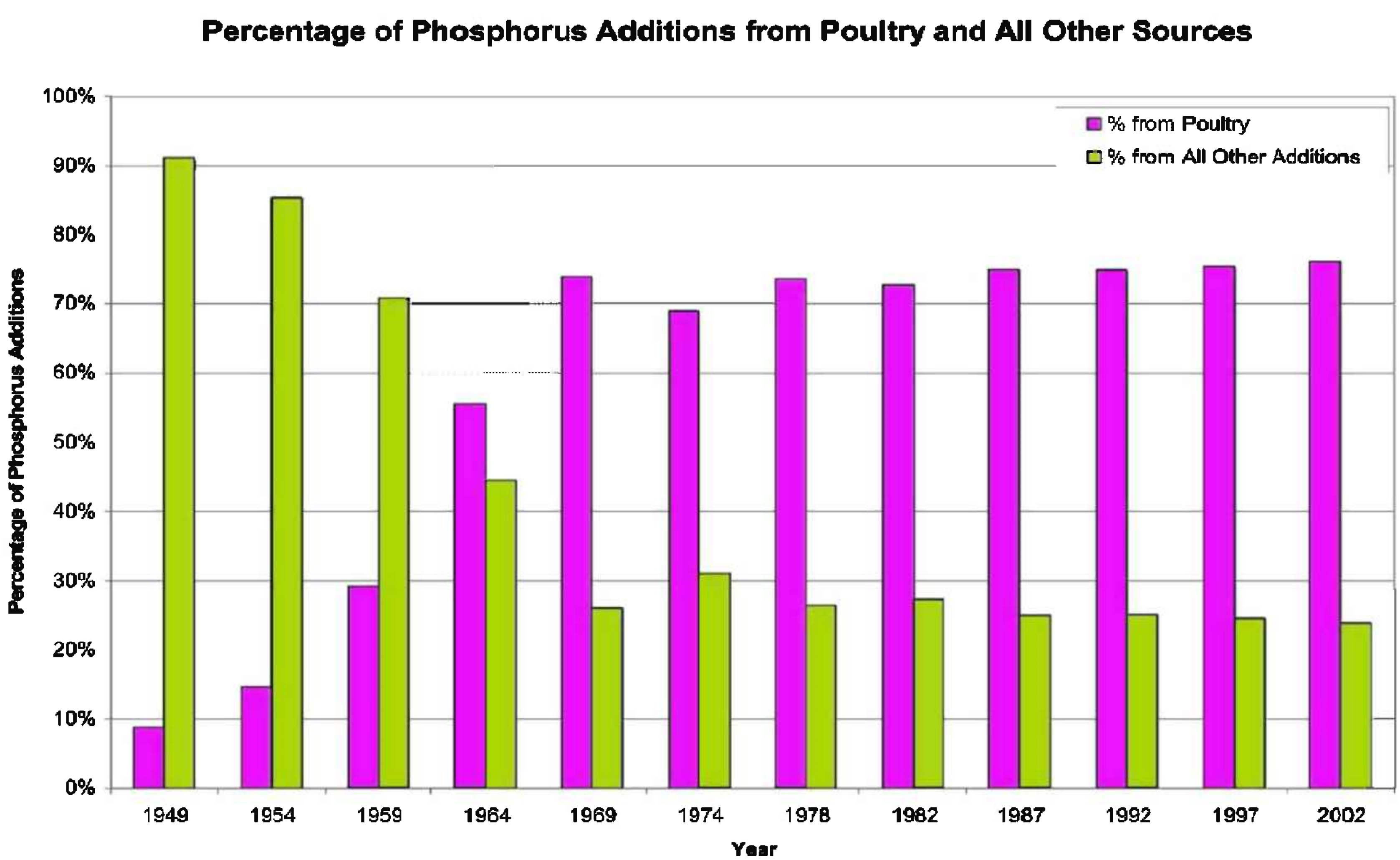

Figure 9. Historical percentage of phosphorus additions from poultry and all other sources (humans, dairy cattle, swine, beef cattle, commercial fertilizer, urban runoff, golf courses, wholesale nurseries, recreational users, and industrial sources)

5.0 CONCLUSIONS

Based on the findings of the study, the following can be concluded:

1. Poultry production is currently responsible for more than 76% of the net annual phosphorus additions to the Illinois River Watershed.
2. Historical data indicates poultry production has been the major contributor of phosphorus to the watershed since 1964. Prior to 1964, dairy cattle were responsible for the majority of the phosphorus contribution.
3. From 1949 to 2002, there was more than 219,000 tons of phosphorus added to the IRW. Almost 68% of that addition, more than 148,000 tons, was attributable to poultry production.
4. Other contributing sources of phosphorus (net additions) include commercial fertilizers (7.5%), dairy cattle (5.2%), humans (3.2%), swine (2.9%), industrial sources – mostly poultry processing facilities (2.7%), and beef cattle (1.7%). The remaining sources of phosphorus evaluated in this study, which include urban runoff, golf courses, wholesale nurseries, and recreational users, are negligible (< 1%).
5. Of the three phosphorus exports from the watershed (harvested crops, harvested deer, and water leaving Lake Tenkiller through the spillway) outflow of phosphorus through the spillway at the south end of Lake Tenkiller was the largest. According to current estimates, the flow of water through the spillway removes just under 1.25% of the total annual phosphorus additions to the watershed. The remaining two phosphorus exports combined remove just over 0.25% of current annual phosphorus additions to the watershed, totaling a 1.5% removal of current phosphorus additions.

6.0 REFERENCES

Ag Census. 1949-2002. United States Census of Agriculture. United States Department of Agriculture; Washington, D.C. United States Census Bureau; Washington, D.C.

Alexander, T.J. 1999. Evaluation of Performance and Management Strategies for a Nursery Irrigation Recycling System Designed for Pollution Control. PhD diss. Stillwater, OK.: Oklahoma State University, Department of Civil Engineering.

ASAE. 2005. Manure Production and Characteristics. ASAE D384.2 MAR2005. St. Joseph, MN.: American Society of Agricultural and Biological Engineers.

ASAE. 2003. Manure Production and Characteristics. ASAE D384.1 FEB2003. St. Joseph, MN.: American Society of Agricultural and Biological Engineers.

Caneday, L. and B. Neal. 1996. Tourism Development Plan: Lake Tenkiller Area. Stillwater, OK.: Oklahoma State University, School of Health, Physical Education and Leisure Studies. Submitted to Cherokee Hill RC&D: Tahlequah, OK.

Caneday, L. 2008. Expert Report.

CDC. 2004. Mean Body Weight, Height, and Body Mass Index, United States 1960-2002. CDC Reference No. 347. Centers for Disease Control and Prevention: Division of Health and Nutrition Examination Surveys.

Copenhaver, M.B. 1991. Evaluation of Nutrient Exports from Three Agricultural Watersheds in the Battle Branch Sub-Basin. MS Thesis. Stillwater, OK: Oklahoma State University, Graduate College.

Daniels, M., T. Daniel, D. Carman, R. Morgan, J. Langston, and K. VanDevender. 2000. Soil Phosphorus Levels: Concerns and Recommendations. University of Arkansas Cooperative Extension Service.

Engel, B. 2008. Personal communication. 10 April 2008. Bernie Engel, Ph.D. is Head of the Department of Agricultural and Biological Engineering at Purdue University.

EPA. 2007. Golf Course Adjustment Factors for Modifying Estimated Drinking Water Concentrations and Estimated Environmental Concentrations Generated by Tier I (FIRST) and Tier II (PRZM/EXAMS) Models. United States Environmental Protection Agency: Washington, D.C. Available at: http://epa.gov/oppefed1/models/water/golf_course adjustment_factors.htm.

EPA. 40 CFR Part 258 Subpart C. Criteria for Municipal Solid Waste Landfills: Operating Criteria. United States Environmental Protection Agency: Washington, D.C.

ERS. 2006. Poultry Yearbook – Tables 71 & 138. Washington, D.C.: USDA Economic Research Service.

Fisher, B.J. 2008. Expert Report: CASE NO. 05-CV-329- GFK-SAJ in the United States District Court for the Northern District of Oklahoma.

Gill, D.R. and K.S. Lusby. 2003. Feeding High Protein Range Cubes. Stillwater, OK: Oklahoma State University Cooperative Extension Service – Publication No. ANSI-3017.

Hallett, G. 2006. Personal communication. 7 August 2006. Golf Course Superintendent, Meadowbrook Country Club: Tulsa, OK.

Haraughty, S. 1999. Comprehensive Basin Management Plan for the Illinois River Basin in Oklahoma. Oklahoma Conservation Commission: Oklahoma City, OK.

Johnson, G. 2007. Personal communication. Dr. Gordon Johnson is a Ph.D. soil scientist.

Lalman, D. Personal communication. 4 April 2008. Dr. Lalman is a Ph.D. Associate Professor and Extension Beef Cattle Specialist, Oklahoma State University.

Lalman, D. 2004. Supplementing Beef Cows. Stillwater, OK: Oklahoma State University Cooperative Extension Service – Publication No. ANSI-3010

L-THIA. Long-Term Hydraulic Impact Assessment Model. http://www.ecn.purdue.edu/runoff/lthianew/. Purdue University.

Martin, D. and D. Hillock. 2002. Lawn Management in Oklahoma. Stillwater, OK. Oklahoma State University Cooperative Extension Service – Publication No. F-6420.

MWPS. 2000. Manure Characteristics. MWPS-18 Section 1. Ames, IA.: MidWest Plan Service.

Nelson, M., K. White, and T. Soerens. 2002. Illinois River Phosphorus Sampling Results and Mass Balance Computation. Arkansas Water Resources Center: Fayetteville, Arkansas.

NMP. 2007. Broiler, Hen, Pullet and Turkey Waste Composition Data Compiled From Nutrient Management Plans (2004 – 2006) Produced by Eucha/Spavinaw Watershed Management Team. Summarized by Lithochimeia, Inc.

ODA. 1993. The Curtis Report – Illinois River Irrigation Tailwater Project 1989-1992. Oklahoma City, OK.: Oklahoma Department of Agriculture – Plant Industry and Consumer Services.

Office of the Secretary of the Environment. 2006. Coordinated Watershed Restoration and Protection Strategy for Oklahoma's Impaired Scenic Rivers: 2006 Update. Oklahoma City, OK.: Office of the Secretary of the Environment, Miles Tolbert.

Masters, R., T. Bidwell, and M. Shaw. 2004. Ecology and Management of Deer in Oklahoma. Stillwater, OK.: Oklahoma State University Cooperative Extension Service – Publication No. F-9009.

OSRC. 1998. The Illinois River Management Plan – 1999. Oklahoma Scenic Rivers Commission (OSRC), Oklahoma State University, National Park Service.

OWRB. 1990. Oklahoma Water Atlas. Oklahoma City, OK.: Oklahoma Water Resources Board.

Pitt, R., A. Maestre, and R. Morquecho. 2004. The National Stormwater Quality Database (NSQD, Version 1.1). Tuscaloosa, AL.: University of Alabama, Department of Civil and Environmental Engineering.

Sarac, K., A. Kohlenberg, L. Davison, J.J. Bruce, and S. White. 2001. Septic System Performance: A Study at Dunoon Northern NSW. On-site '01 – Advancing On-site Systems Conference: University of New England, Armidale, NSW, 25-27 Sept, pp: 323-330.

Slaton, N.A., K.R. Brye, M.B. Daniels, T.C. Daniels, R.J. Norman, and D.M. Miller. 2004. Nutrient Input and Removal Trends for Agricultural Soils in Nine Geographic Regions in Arkansas. J. Environ. Qual. 33: 1606-1615.

Smolen, M. D., P.L. Kenkel, D.S. Peel, and D.E. Storm. 1994. In Proc. Mass Balance Analysis of Nutrient Flow Through Feed and Waste in the Livestock Industry. Great Plains Animal Waste Conference on Confined Animal Production and Water Quality. GPAC Publication Number 151. Great Plains Agricultural Council, Denver, CO.

South Central Golf Magazine. 2006. Volume 13, No. 1.

UIUC. 2006. Wild Game – Nutrient Content. Urbana-Champagne, IL.: University of Illinois Extension Solutions Series: Food and Nutrition. Available at: www.solutions.uiuc.edu.

USDA. 1992. Agricultural Waste Management Field Handbook. Washington, D.C.: USDA – Soil Conservation Service.

Van Waasbergen, R. 2007. Personal communication. Dr. Robert van Waasbergen is a Ph.D. geographer.

APPENDIX A

Projected Fertilizer Sales from 1951 – 2002

Provided by Dr. Gordon Johnson